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Voltage Profile Improvement and Power Loss Reduction by DG Placement in a Distribution Feeder in Western Nepal

by

Youb Raj Rawat

A THESIS

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CERTIFICATE OF APPROVAL

The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance, a thesis report entitled “Voltage Profile Improvement and Power Loss Reduction by DG Placement in a Distribution Feeder in Western Nepal” submitted by Youb Raj Rawat in partial fulfillment of the requirement for the degree of Master of Science in Electrical Engineering in Power System.

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ABSTRACT

A power system is composed of various components that work together to generate, transmit, and distribute electricity to consumers. The distribution system completes the process of delivering electricity to the ultimate users or customers. Radial, loop and network distribution system are basic three types of distribution system design. The radial distribution system is simple and cheapest to build and is extensively used in sparse populated area. However, due to the existence of higher resistance, longer length and lower voltage level in the distribution system network, electrical energy is continuously lost. The distribution system is often viewed as the weakest link in the power system. The ratio of resistance to reactance in a distribution system is higher as compared to transmission system and significant voltage drop along a distribution feeder can cause substantial power and energy losses. Due to Joules effect power loss occurs in distribution feeder account for as much as 13% of the generated energy (1). Therefore, reducing losses in the distribution system is a major challenge for many utility companies worldwide. As per NEA Annual Report 2020/021, in INPS distribution system loss is 10.86%. Reduction of loss in distribution system has been an important area of focus from the time when the development of interconnected power systems. To increase overall effectiveness of the electrical power distribution system, it is crucial to reduce active power loss in the system. By supplying a portion of the reactive demand locally with the aid of capacitors, the active power loss caused by the reactive component of branch current can be decreased (2). Similarly with the help of technique “Reconfiguration of distribution system” power loss of a distribution system can also be reduced (3).

The restructuring of the electricity market, improvements in energy generation technology and agreements to reduce greenhouse gas emissions have led to an increase in the use of distributed generation. Distributed generation is not only seen as a way to provide energy, but also as a way to improve the performance of distribution systems and enhance system reliability. This research work comprises finding optimal size and location of four different types of distributed generation (DG) unit based on power factor for loss reduction in 33 bus IEEE radial distribution system (RDS) using “exact power loss” expression using MATLAB. The various types of DG used are I) DG capable of delivering real power only

II) DG capable of delivering reactive power only III) DG capable of delivering real and reactive power IV) DG capable of delivering real power and absorbing reactive power are taken into consideration. After validation of MATLAB program in IEEE 33-bus radial distribution system it is implemented in Kohalpur-Surkhet primary distribution system (practical feeder). During base case in practical feeder the loss percentage is 30.79% during peak load and voltage profile is minimum at bus 14 (Budbudi S/S) which stands at 25.27 kV. After the insertion of optimal size DGs capable of injecting real power only (7.68 MW at bus 14), loss of the system is considerably reduced to 1.5% during peak load and voltage profile of the system is minimum at bus 14 which is 31.61 kV. Similarly after the insertion of optimal size DGs capable of delivering reactive power only (2.30 MVAR at bus 9), loss of the system reduces to 25.76% during peak load and voltage profile of the system is minimum at bus 9 which stands at 26.93 kV. When we consider the optimal size of DGs capable of delivering both real and reactive power (7.47 MVA at bus 14), loss of the system reduces considerably to 2.09% during peak load and voltage profile of the system is minimum at bus 19 which stands at 32.77 kV. Hence Distributed generation is important because it enhances energy security, improves reliability, facilitates renewable energy integration, supports load management, offers economic benefits, reduces environmental impacts, and empowers energy consumers. These factors make it a vital component for transition to a more sustainable, resilient, and decentralized energy system.

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LIST OF ABBREVIATIONS AND SYMBOLS

p.u.	Per unit
RDS	Radial Distribution System
PDS	Primary Distribution System
NEA	Nepal Electricity Authority
KSPDS	Kohalpur-Surkhet Primary Distribution System
kVA	Kilovolt Ampere
kW	Kilo Watt
MVA	Megavolt Ampere
LSF	Loss Sensitivity Factor
R	Resistance
X	Reactance
BIBC	Bus Injection to Branch Current
BCBV	Branch Current to Bus Voltage
S	Complex Power
P	Real Power
Q	Reactive Power
V	Voltage
I	Current
DLF	Distribution Load Flow
S/S	Substation
KCL	Kirchhoff's Current Law
KVL	Kirchhoff's Voltage Law
B	Branch Current
C	Capacitor current
GA	Genetic Algorithm
DG	Distributed Generation
RDS	Radial Distribution System
MATLAB	Matrix Laboratory

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CHAPTER 1: INTRODUCTION

1.1 Overview

Distributed generation (DG) refers to the production of electricity from numerous small scale power sources typically ranging from less than a kW to tens of MW that are situated close to the point to consumption as opposed to the centralized power plant. It entails producing electricity from a variety of sources, including fuel cells, micro turbines, wind turbines, solar panels and small hydroelectric plants.

Recently, there is a growing trend of incorporating distributed generation (DG) into distribution system globally. Distributed generation (DG) can assist in minimizing energy losses, reducing peak demand losses, and enhancing the voltage profile, stability, and power factor of power networks. Distributed generation technologies, operating within the framework of the smart grid concept, serve as the foundation of the global electric distribution network because it do not requires construction of new transmission and distribution line, loading of line can considerably be reduced, increases reliability of electrical system, decreases the cost of interruption and energy loss (4). But due to some limitations, if the size and location of DG are not selected appropriately, leads the system loss higher than that of system without DG placement.

1.2 Problem Statement

The modern power distribution network is facing increasing load demand, excessive expansion of distribution system resulting higher losses, reduces voltage quality. Active and reactive compensation are necessary to enhance the voltage profile and prevent voltage collapse. The distribution system has a high R/X ratio when compared to the transmission system, resulting in significant power losses and a decrease in voltage magnitude along radial distribution lines. Losses in distribution networks are significantly higher than in transmission networks, this directly affects the financial situation and overall effectiveness of distribution utilities.

Various strategies can be implemented to minimize these losses, including modifying the network configuration, installing shunt capacitors, and strategically placing distributed generators. Distributed generators is also known as active source which can help to reduce energy losses, peak demand losses and improve the network voltage profile, stability and power factor of distribution system. The use of DG in the distribution system can help to address the issues of reduction in voltage magnitude and increase in distribution losses that can lead to inefficiencies in the system.

1.3 Objectives of the Thesis

The objective of this thesis is

- Placement of DG based on operating power factor in a Kohalpur-Surkhet primary distribution system for minimum power losses and increment of voltage profile using MATLAB (Matrix Laboratory) program.

1.4 Scope of this Thesis

- Load flow of IEEE 33 bus radial distribution system and 33 kV real practical distribution system of Nepal (Kohalpur-Surkhet-33 kV Tr. Line).
- Finding the optimal location on the real practical distribution system for placement of DG for the optimum results for power loss reduction and voltage profile improvement.
- Research on the impact of DG on radial distribution system, including the effects on system voltage, power flow, and power quality.
- The effects of different forms of distributed generation (DG) on a radial distribution system can be examined.

1.5 Assumption and Limitations

- The active and reactive powers of the node are assumed to be known and time invariant.
- The sizing and location of DG is considered at the peak load only.
- Constant power factor distributed generators are taken into account.
- The modeling of distributed generation is not considered.
- Distributed generation sources are evenly distributed throughout the network.

1.6 Outline of the Report

This thesis report is organized in five chapters.

- The first chapter discusses about the background introduction of the topic, states the problem, objective and scope of the thesis.

- In the second chapter of this thesis, literature review about load flow analysis of radial distribution system, voltage sensitivity index and optimal location and size of distributed generation in radial distribution system is discussed. Furthermore, different techniques employed by prominent authors for the same are explained.
- The third chapter explains about the methodology used for this thesis in detail. This includes the formation of BIBC and BCBV matrix, load flow algorithm, VSF for finding most probable bus location for compensation, optimal size and placement of distributed generation for maximum loss reduction and improvement in power quality
- In the fourth chapter the results are obtained for the base case load flow. Power loss and voltage profile of RDS is obtained. The location for placement of DG for reduction of power loss and improvement of power quality are determined. Using exact power loss formula the optimum value and location of DG for various types and power factor are discussed for minimum power loss and efficiency of system and are summarized
- The fifth chapter concludes the result of this thesis, and suggests future works that could be performed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A distributed power generation system refers to the integration of small power generation sources, such as solar panels and wind turbines, into the traditional power grid. In a radial distribution network, the DG system is connected to the network at the distribution level rather than the transmission level.

Recent studies have shown that the integration of DGs into radial distribution grids offers many benefits, such as improved system reliability, improved power quality, and reduced transmission and distribution losses. However, DG integration also brings new challenges for power system operation and control, including maintains power flow and voltage stability. Research has revealed that incorporating DGs into radial power distribution networks can provide advantages such as heightened system stability, enhanced power quality, and diminished transmission and distribution losses. However, incorporating DGs also poses new difficulties for managing and regulating the power system, including preserving power flow and voltage stability. When integrating a significant amount of distributed generation (DG), it is crucial to thoroughly assess the impact on the power system. This evaluation ensures that the implementation of DGs does not have adverse effects on quality of power, reliability of system, and control system of utility.

2.2 Literature Survey

Y. Al-Mahroqi and all (1), the work in this paper is focused on reduction of technical loss in a radial distribution system. Power loss occur in distribution network due to Joule's effect is 13% of the generated energy. It also describes about the technical and sources of non-technical loss of the distribution system. Power loss and voltage improvement of Oman distribution system (having loss of 18.9% of total units generated) has been analyzed using ETAP. The consideration assumed is a) Capacitor placement b) Construction of distribution line c) Up gradation of S/S transformers. It is observed that with the application of these technique the power loss of Oman distribution system will be reduced by 60%.

Sushma Lohia, Om Prakash Mahela, Shree Ram Ola (2), the work on this paper is focused on optimal placement of capacitor bank is a radial distribution system for loss reduction. Capacitor is used to compensate the reactive power of the distribution system. Excessive capacitor placement results leading power factor which is undesirable because it produce excessive heat loss. Therefore optimal size and proper placement of capacitor bank is the key aspect for the power system.

P. Ravi Babu, Sushma Pasunuru, Gattu Vaishnavi (3), the work in this thesis paper is focused on reduction in real power loss of a radial distribution system. Among various techniques this paper uses the method of reconfiguration of distribution system using switches. Among all various AI-based techniques, AI technique, Genetic algorithm is implemented.

M.F Shaaban (4), the work on this paper is focused on the cost damage due to loss of power in distribution system before and after placement of distributed generation. Here, modeling of DG and load model has been carried out and details are presented; than the objective function and constraints. Genetic Algorithm is used in the next section to find optimal sizes and location of installed DG. Maximum penetration is limited to 60 percent of the substation rated power. This paper evaluates the cost of interruption and cost of energy loss of the distribution system when renewable DG is connected.

Carmen L.T. Borges , Djalma M. Falcalo (5), the work on this paper is focused on the approach of optimal allocation of distributed generation and sizing in radial distribution system for reducing electric losses and improvement in reliability. This context, a genetic algorithms technique is employed to optimize the process, incorporating methods for assessing the impacts of distributed generation (DG) on system reliability, losses, and voltage profile. The power flow method is utilized to analyze losses and voltage profile specifically for radial networks. Additionally, reliability indices are evaluated using an analytical method that has been adapted to handle multiple generations.

Duong Quoc Hung, Nadarajah Mithulananthan (6), the work on this paper is focused on validation of analytical expression. Here "Exact Loss Formula" is used to derive an expression for finding the maximum capacity of distributed generation at each bus of distribution system resulting minimum power loss. Distributed generations are classified into four types based on its operating condition. Type 1 DG capable of delivering real power only. Type 2 DG capable of delivering reactive power only. Type 3 DG capable of delivering real and reactive power. Type 4 DG capable of delivering real power and consuming reactive power. The proposed methodology is compared with exhaustive load flow; the result of loss reduction is almost the same. How-ever exhaustive load flow method requires large computation time than that of IA.

Dinakara Prasad Reddy P (7), the work on this paper is focused on finding the appropriate position of capacitor with the help of Loss Sensitivity Factor (LSF) and Genetic Algorithm for the placement of capacitors on the primary feeders of the radial distribution system to reduce the power loss and increase the voltage profile. The conclusion of the paper is by inserting capacitor in appropriate position and size power loss in the radial distribution system can be greatly reduced.

Jen-Hao Teng (8), the work on this paper is focused on the load flow of unbalanced radial distribution system. Many load flow techniques designed for distribution load flow has been proposed in the literature. From those method Gauss implicit Z-matrix method has been used widely. In this paper BIBC and BCBV matrix are developed using topological characteristics of distribution network to make the direct solution possible. Comparison of above techniques shows that proposed method is both robust and efficient.

Parham Karimi-Zare, Hossein Seifi (9), the work on this paper is focused on penetration level of distributed generation. The penetration level of distributed generation depends upon operation mode, capacitive and inductive mode line current and bus voltages.

CHAPTER 3: METHODOLOGY

3.1 Introduction

To determine the optimal placement of Distributed Generation (DG) in a distribution system, it is necessary to repeatedly perform load flow analysis. In the text book, numbers of load flow solution techniques such as Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow method are available. These methods have been implement in transmission systems having less number of buses and lines having low resistance. Distribution system consists large number of buses and has high R/X ratio, inverse of admittance matrix and Jacobian matrix may leads to singular matrix resulting ill condition. Therefore, conve0ntional load flow method may not be suitable.

In this thesis, the line parameters such as conductor type & its length, sending bus and receiving bus are known along with loading parameters such active and reactive power consumption at each node. From such line parameters, BIBC and BCBV Matrix are formed which are used to solve load flow problem yielding voltage profile, bus injection current and branch current of the given system for different loading parameters. Loss sensitivity Factors are then utilized to predict sensitive contestant buses for DG placement. As soon as contestant locations are identified, DG size is identified using the concept of maximum loss reduction criteria. Finally the load flow analysis is done in compensated system for calculating power loss and voltage profile.

3.2 Load flow of RDS.

The load flow method for the distribution system under balanced operating condition employing constant load model is based on the two developed matrices bus current injection to branch current (BIBC) and branch current to bus voltage (BCBV). These matrices solely depends upon the topological structure of distribution systems (5).

The BIBC matrix shows the relations between the bus current injections and the branch currents, whereas the BCBV matrix has the relations between the branch currents and bus voltages. The load flow analysis in distribution system utilizes the product of the BIBC and BCBV matrices to solve the load flow problem. This method is known for its simplicity, efficiency in terms of time, and robustness. The approach employed in this thesis to conduct load flow analysis for radial distribution systems can be comprehended by

1. Equivalent current injection
2. Formation of BIBC matrix
3. Formation of BCBV matrix

3.2.1 Equivalent current injection

In this approach, the concept of equivalent current injection is used. At bus i, where the complex power is given as Si, the corresponding equivalent current injection during the kth iteration of the solution can be calculated as follows:

$$S_{\mathrm{i}} = \mathrm{P_i} + jQ_{\mathrm{i}} \qquad \text{- (3.1)}$$

$$\mathrm{I_i^k} = \left(\frac{\mathrm{P_i + jQ_i}}{\mathrm{V_i^k}}\right)^{*} \qquad \text{- (3.2)}$$

Where,

S_i - complex power at the i^{th} bus.

P_i - real power at the i^{th} bus.

Q_i - reactive power at the i^{th} bus.

V_i^k - bus voltage at the k^{th} iteration for i^{th} bus.

I_i^k is the equivalent current injection at the k^{th} iteration for i^{th} bus.

3.2.2 Formation of BIBC matrix

The process of formulating the Bus Current injection to Branch-current (BIBC) matrix is illustrated using a simple distribution system depicted in Figure 3.1.

If the current injections at each bus are known, the current flowing through each branch can be determined using Kirchhoff's Current Law (KCL). Figure 3.1 illustrates the current flowing through each branch Bc1, Bc2, Bc3, Bc4, and Bc5, which can be expressed as follows:

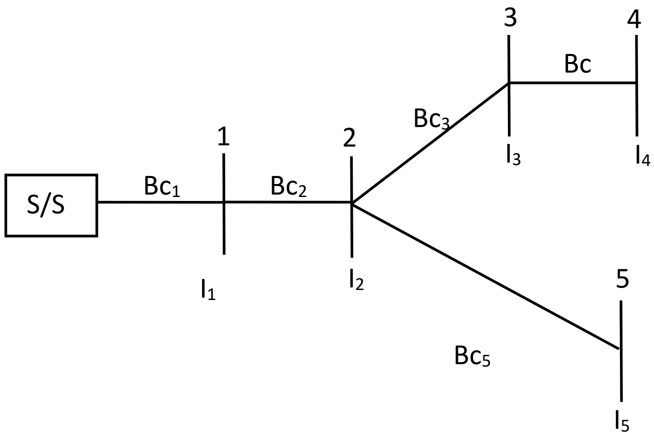


Figure 3. 1 Simple radial distribution system.

Current flowing through each branch can be expressed as

$Bc_5 = I_5$ - (3.3)

$Bc_4 = I_4$ - (3.4)

$Bc_3 = I_3 + I_4$ - (3.5)

$Bc_2 = I_2 + I_3 + I_4 + I_5$ - (3.6)

$Bc_1 = I_1 + I_2 + I_3 + I_4 + I_5$ - (3.7)

From the above equation no. (3.3), (3.4), (3.5), (3.6), and (3.7) the BIBC matrix can be obtained as:

$$\begin{bmatrix} B_{c1} \\ B_{c2} \\ B_{c3} \\ B_{c4} \\ B_{c5} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} \quad - (3.8)$$

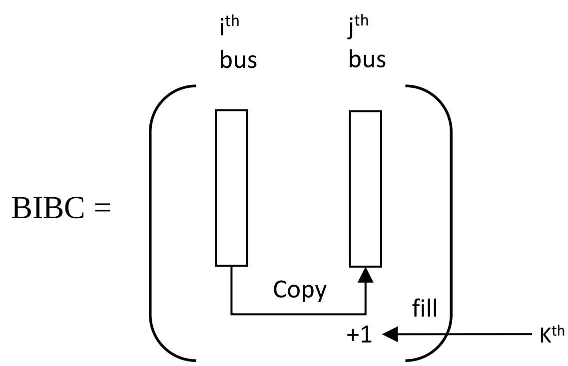
In general it can be expressed as:-

$[Bc] = [BIBC][I]$ - (3.9)

The BIBC matrix for the aforementioned network can be constructed using following procedure

Step 1: In the network having n buses and m branchs, the size of the BIBC matrix is m × (n - 1).

Step 2: If a branch (Bk) is suitated between Bus i and Bus j, copy the column of the ith bus from the BIBC matrix to the column of the jth bus. In the corresponding kth row and jth bus column, fill in the value n + 1. The process is described as follows:



Step 3: Repeat step (2) until all the branch are included in the BIBC matrix.

3.2.3 Formation of BCBV matrix

The BCBV (Branch Current to Bus Voltage) matrix illustrates the relationship between branch currents and bus voltages in a distribution system. These relationships can be easily obtained using KVL. In Figure 3.1, the voltages of Bus 1, Bus 2, and Bus 3 are calculated as follows:

$$V_1=V_0-B_1Z_{01} \quad - (3.10)$$

$$V_2=V_1-B_2Z_{12} \quad - (3.11)$$

$$V_3=V_0-B_3Z_{23} \quad - (3.12)$$

Hence by substituting eq. (3.10) and eq. (3.11) the voltage of bus 3 can be rewritten as

$$V_3 = V_0 - B_1Z_{01} - B_2Z_{12} - B_3Z_{23} \quad - (3.13)$$

The node voltages depends upon the station voltage, branch currents and line parameters. Related techniques can be applied to calculate the bus voltages for other buses in the system. By using these techniques, the Branch Current to Bus Voltage can be written in matrix form as shown below.

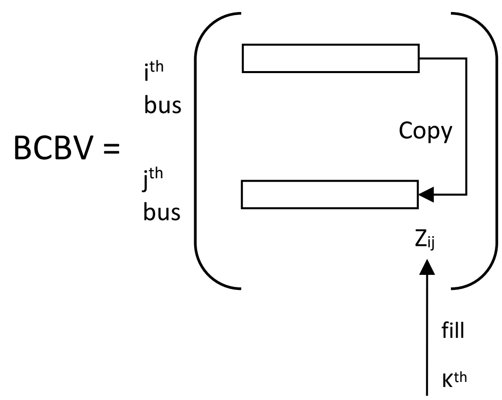
$$\begin{bmatrix} V_0 \\ V_0 \\ V_0 \\ V_0 \\ V_0 \end{bmatrix} - \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix} = \begin{bmatrix} Z_{01} & 0 & 0 & 0 & 0 \\ Z_{01} & Z_{12} & 0 & 0 & 0 \\ Z_{01} & Z_{12} & Z_{23} & 0 & 0 \\ Z_{01} & Z_{12} & Z_{23} & Z_{34} & 0 \\ Z_{01} & Z_{12} & 0 & 0 & Z_{25} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \qquad - (3.14)$$

i.e. $[\Delta V] = [BCBV]\,[B]$ - (3.15)

To form the BCBV matrix for Figure 3.1, the following steps can be followed:

Step 1: Determine the dimension of the BCBV matrix based on number of branches (m) and the number of buses (n). The size of the BCBV matrix would be $(n - 1) \times m$.

Step 2: Identify the branches (Bk) located between bus i and bus j. For each branch, replicate the row of the i_{th} bus in the BCBV matrix and assign it to the row of the j_{th} bus. Then, replace the impedance of the line (Z_{ij}) in the corresponding cell of the j_{th} bus row and the kth column.



This is explained below:-

Step 3: Repeat the above procedure till all the branches gets include in BCBV matrix.

The formulations of the relationships between current injections at bus nodes and the corresponding voltage levels can be expressed as follows:

$[\Delta V] = [BCBV]\,[B]$ - (3.16)

Or, $[\Delta V] = [BCBV]\,[BIBC]\,[I]$ - (3.17)

Or, $[\Delta V] = [DLF]\,[I]$ - (3.18)

The load flow solution can be found by solving following two equations iteratively.

$$I_i^k = I_i^r V_i^k + I_i^i V_i^k = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \qquad - (3.19)$$

The load flow problem can be solved using DLF matrix which is explained above.

3.2.4 Algorithm of Load Flow

The proposed Load Flow method can be summarized as follows:-

1. Input data.
2. Compute BIBC Matrix
3. Compute BCBV Matrix
4. Form DLF Matrix such that

   [DLF] = [BCBV] [BIBC]
5. Iteration k=0
6. k=k+1
7. Solve for three-phase power flow and Update voltages
8. If max($[I_i^{k+1]}$ –$[I_i^k]$) > tolerance, go to 6
9. Else stop

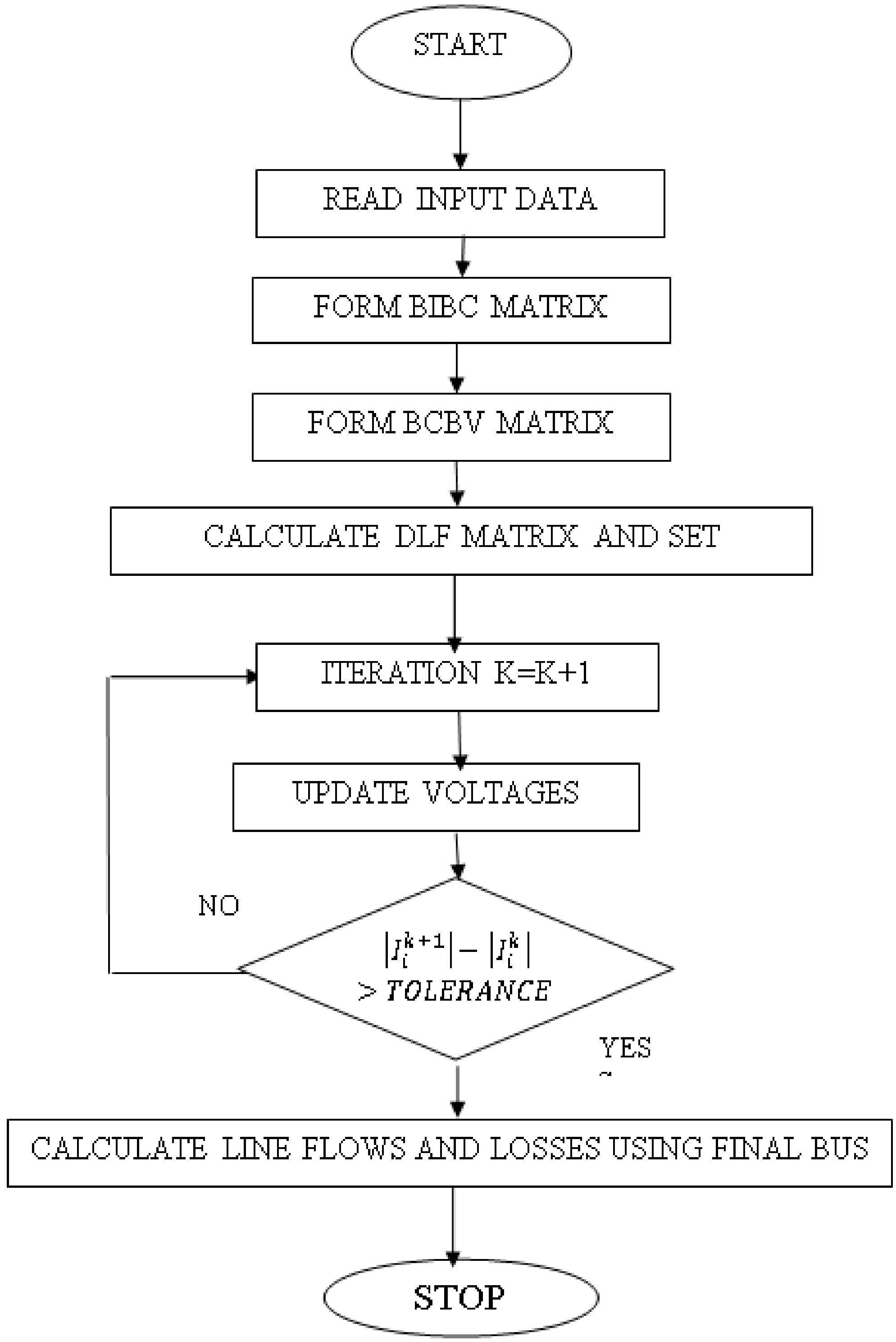


Figure 3. 2 Flow chart for load flow analysis using DLF method.

3.3 Loss sensitivity factor

Loss sensitivity factor is used to identify the location of DG in radial distribution system. This factor enable us to find the bus location of bus at which distributed generation is to be placed for biggest loss reduction. Hence, these sensitive buses can be considered as potential contestant buses for the optimal placement of distributed generations. Evaluating these contestant buses allows for a reduction in the search space during the process of determining the optimal locations for distributed generation placement. Since only a limited number of buses are eligible for compensation, the expense associated with implementing distributed generation can also be decreased.

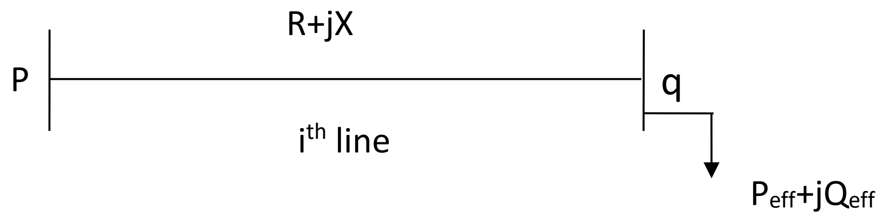


Figure 3. 3 SLD of two bus system network.

Active power loss in the i^{th} line is given by, $[I_i^2] * R[i]$ which can be expressed as

$$P_{lineloss}[q] = \frac{\left(P_{eff}^2[q]+Q_{eff}^2[q]\right)R[i]}{V[q]^2} \qquad - (3.20)$$

Similarly, reactive power loss in the i^{th} line is given by, $[I_i^2]*X[i]$, and is expressed as

$$Q_{lineloss}[q] = \frac{\left(P_{eff}^2[q]+Q_{eff}^2[q]\right)X[i]}{V[q]^2} \qquad - (3.21)$$

Where

Peff [q] = Total effective active power supplied beyond the bus 'j'

Qeff[q] = Total effective reactive power supplied beyond the bus 'j'

Now, the Loss Sensitivity Factors can be calculated as

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{2*Q_{eff}[q]*R[i]}{V[q]^2} \;,\; \frac{2*Q_{eff}[q]*X[i]}{V[q]^2} \qquad - (3.22)$$

3.3.1 Selection of Contestant Buses Based on Loss Sensitivity Factor

Loss sensitivity factor is an approach used to find the location of bus at which the distributed generation is to be be placed. This method helps us to reduce the search space for the optimization procedure. The loss sensitivity factor (LSF) are calculated from the base case load flow and are arranged in descending order for all the braches of distribution system. The descending order of the LSF vector (problocation[i]) will decides the sequence at which buses are to be considered for compensation. This sequence is purely governed by the partially derivate of line losses with respect of effective value of reactive power ($\frac{\partial Q_{\mathrm{lineloss}}}{\partial Q_{\mathrm{eff}}}$). Hence, Loss Sensitive Coefficient factor become very powerful and useful technique for DG allocation and placement. Considering the base case voltage magnitude of V[i]/0.95 are calculated for each buses named as V_{norms} vector. If the value of V_{norms} of problocation[i] < 1.01 are considered as the contestant buses which requires compensation. If the voltage at a bus in the sequence list is healthy (i.e., V_{norms}>1.01) such bus doesnot requires compensation and that bus will not be listed in the 'problocation' vector. The 'problocation' vector provides details on the prospective or potential contestant s for buses to be placed in DG.

3.3.2 Algorithm for location

The proposed method can be summarized as follows:-

1) Get the voltage (in p.u.) for each buses.

2) Calculate P_{eff} and Q_{eff} for each bus.

3) Calculate reactive power loss in the k^{th} bus as

$$Q_{\mathrm{lineloss}}[q] = \frac{\left(P_{\mathrm{eff}}^2[q] + Q_{\mathrm{eff}}^2[q]\right) X[i]}{V[q]^2}$$

4) Obtain loss sensitivity factors$\frac{\partial Q_{\mathrm{lineloss}}}{\partial Q_{\mathrm{eff}}}$.

5) Obtain the LSFs in descending order for the compensation and store in problocation [i] vector and Normalize bus voltages as V_{norm}=V/0.95.

6) Obtain the problocation vector for the buses whose V_{norm} is less than 1.01 p.u.

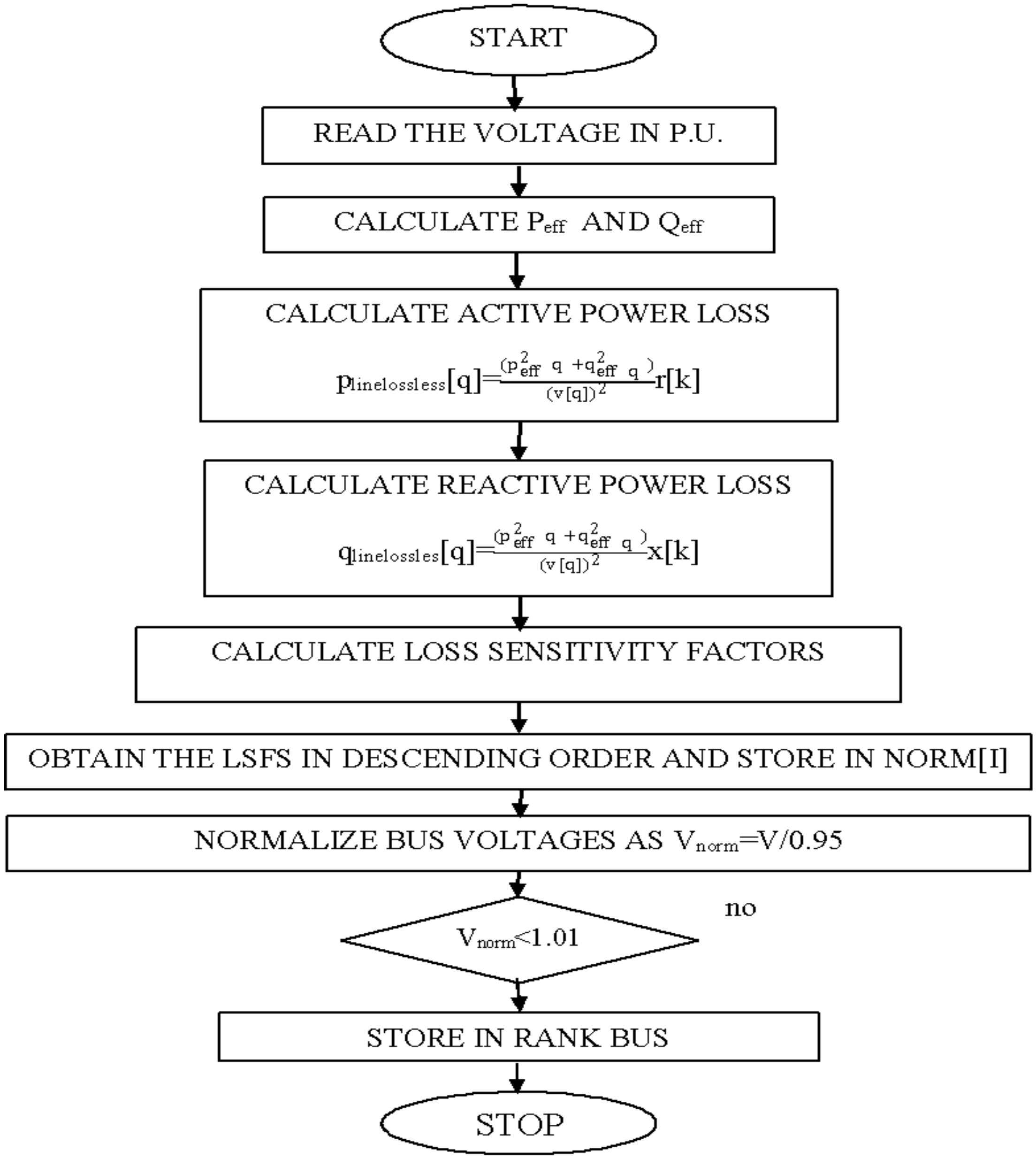


Figure 3. 4 Flow char of LSF

3.4 DG sizing and placement

A distributed generator, or DG, is a small-scale power generation unit that is connected to the distribution network, as opposed to the transmission network. These generators can take many forms, including solar panels, wind turbines, fuel cells, and small-scale combustion turbines, and they can be connected to the distribution network at various points, such as substations, feeders, or even at individual customer premises. The use of DGs is becoming increasingly common as a way to increase the penetration of renewable energy sources and decrease dependence on fossil fuels. DGs also have the potential to improve system reliability, decrease transmission and distribution losses, and provide voltage support to the distribution network. DGs can operate in one of two ways: islanded mode or grid-connected mode. In islanded mode, the DG operates independently from the grid and supplies power directly to local loads. In grid-connected mode, the DG is connected to the grid and can supply power to or absorb power from the grid, depending on the power balance.

3.4.1 Problem formulation:

The objective function for minimizing total real power loss in a radial distribution system can be expressed as follows:

F=min (P_L)

$$P_L = \sum_{i=1,j=1}^{N,N} \left(a_{ij}\left(P_i P_j + Q_i Q_j\right) + b_{ij}\left(Q_i P_j - P_i Q_j\right) \right) \qquad - (3.23)$$

Where

$$a_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\delta_i - \delta_j),\ b_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j), \qquad - (3.24)$$

$V_i \angle \delta_i$	voltage at bus i^{th}
$r_{ij} + jx_{ij}$	ij^{th} element of [Z_{bus}] impedance matrix
P_i , P_j	active power injection at i^{th} and j^{th} buses, respectively
Q_i , Q_j	reactive power injection at the i^{th} and j^{th} buses, respectively
N	number of buses;

Where,

$P_i = P_{Gi} - P_{Di}$ and $Q_i = Q_{Gi} - Q_{Di}$ - (3.25)

And voltage $V_{min} \leq V_i \leq V_{max}$ - (3.26)

3.4.2 Types and sizing of DG:

DG can be classified into four major type based on their terminal characteristics in terms of real and reactive power delivering capability as follows.

a) Type-1: DG capable of injecting active power only (Photovoltaic, Micro turbine, fuel cells)
b) Type-2: DG capable of injecting reactive power only (synchronous compensator such as gas turbine)
c) Type-3: DG capable of injecting real and reactive power (based on synchronous machine like cogeneration, gas turbine etc.)
d) Type-4: DG capable of injecting real and consuming reactive power (based on induction generator like wind turbine)

Assumptions were made are (i) the active and reactive power of the distributed generators varies linearly (ii) load connected to the network is considered as constant power load.

While we consider active power and reactive power of the DGs varies linearly we can write

$Q_{Gi} = S^*P_{Gi}$ - (3.27)

$S = (\text{sign}) \tan(\cos^{-1}(pf))$ - (3.28)

Substituting the value of $Pi = P_{Gi}-P_{Di}$ & $Q_i = S^*P_{Gi} - Q_{Di}$ in equation (3.23) we get

$$P_L = \sum_{i=1,j=1}^{N,N} \Big(a_{ij}\big((P_{Gi} - P_{Di})P_j + (SP_{Gi} - Q_{Di})Q_j\big) + b_{ij}\big((SP_{Gi} - Q_{Di})P_j - (P_{Gi} - P_{Di})Q_j\big)\Big) \quad - (3.29)$$

if the partial derivate of equation (3.29) w.r.t. the active power injection from DG at bus I equates to zero, the active power loss of a network becomes minimum. After simplification we get,

$$P_{Gi} = \frac{a_{ii}(P_{Di}+SQ_{Di})+b_{ii}(SP_{Di}+Q_{Di})-X_i-SY_i}{S^2a_{ii}+a_{ii}} \quad - (3.30)$$

Where,

$X_i = \sum_{j=i,j\neq i}^{n}(a_{ij}P_j - b_{ij}Q_j)$ - (3.31)

$Y_i = \sum_{j=i,j\neq i}^{n}(a_{ij}Q_j + b_{ij}P_j)$ - (3.32)

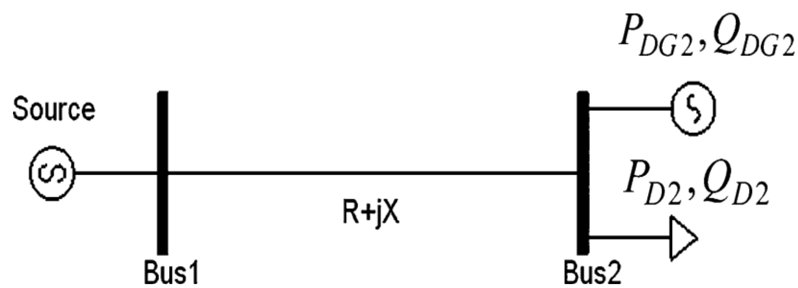


Figure 3. 5 SLD of two bus system network.

The power factor of the distributed generation (DG) depends on the type of DG and its operating conditions. When determining the p.f. of DG, the optimal capacity of DG at each bus i, which results in minimum loss, can be calculated using the following methods

i) Type 1 DG: For this type of DG p.f. is unity, i.e. S=0, PF_{DG}=1, from above equation the optimal size of DG at each bus I for minimum losses is given by

$P_{DGi} = P_{Di} - \frac{1}{a_{ii}}[\ b_{ii}Q_{Di} + X_i\ ]$ - (3.33)

ii) Type 2 DG: For this type of DG p.f. is zero, i.e. S=∞, from above equation the optimal size of DG at each bus I for minimum losses is given by

$Q_{DGi} = Q_{Di} + \frac{1}{a_{ii}}[\ b_{ii}P_{Di} - Y_i\ ]$ - (3.34)

iii) Type 3 DG: For this type of DG p.f. is assumed 0<PF<1, sign = +1 and S is constant, the optimal size of distributed generation is given by eq. (3.30).

iv) Type 4 DG: For this type of DG p.f. is assumed -1<PF<0, sign = -1 and S is constant, the optimal size of distributed generation is given by eq. (3.30).

Considering power factor of DG and load curve of primary distribution feeder the optimal location and size of DG can be found.

CHAPTER 4: RESULTS AND DISCUSSION

In this chapter, the outcomes obtained from the implementation of the aforementioned algorithm are presented. The algorithms were developed using the MATLAB environment to execute distribution load flow (DLF), compute real and reactive power losses, and determine the optimal size of distributed generations. The line and load data were first stored in Microsoft office excel sheet and the stored data were read from MATLAB. The proposed analytical methods can handle four different types of DG, result of type 1-DG, type 2-DG and type 3-DG i.e., DG capable of delivering reactive power only, DG capable of delivering real power only and DG capable of delivering real and reactive power respectively is accounted herein Thesis. IEEE 33-Bus Radial Distribution test system have been used to test and validate the analytical expression “Exact Loss Formula”. After validation, the optimum size and location of various type of Distributed Generation is performed in 33 kV Kohalpur-Surkhet primary distribution system for maximum loss reduction and voltage profile improvement.

Assumption and constraints made under this study are

- Only the peak load is taken into account when determining the size and placement of DG systems.
- The lower and upper voltage of the system is set between 0.95 p.u and 1.05 p.u.

4.1 Case I - IEEE 33-Bus Radial Distribution System

The algorithm described has been tested on IEEE 33-bus radial distribution systems (RDS). This system consists of 33 buses and 32 lines and has a voltage of 12.66 kV. The total loading was found to be 3715 kW and 2300 kVAR. The line data and load data of 33-bus radial distribution system can be found in ANNEX B. The calculations are performed in per unit system. The base voltage and base MVA are assumed to be 12.66 kV and 100 MVA respectively. Hence,

Base current $=\frac{\text{Base MVA}}{\sqrt{3}*\text{Base KV}}=\frac{100\text{ MVA}}{\sqrt{3}*12.66\text{ KV}}=$ 456.05A

Base impedance $=\frac{\text{Base KV}^2}{\text{Base MVA}}=\frac{12.66^2}{100}=$ 1.602Ω

4.1.1 Bus voltages in an uncompensated IEEE 33-bus RDS

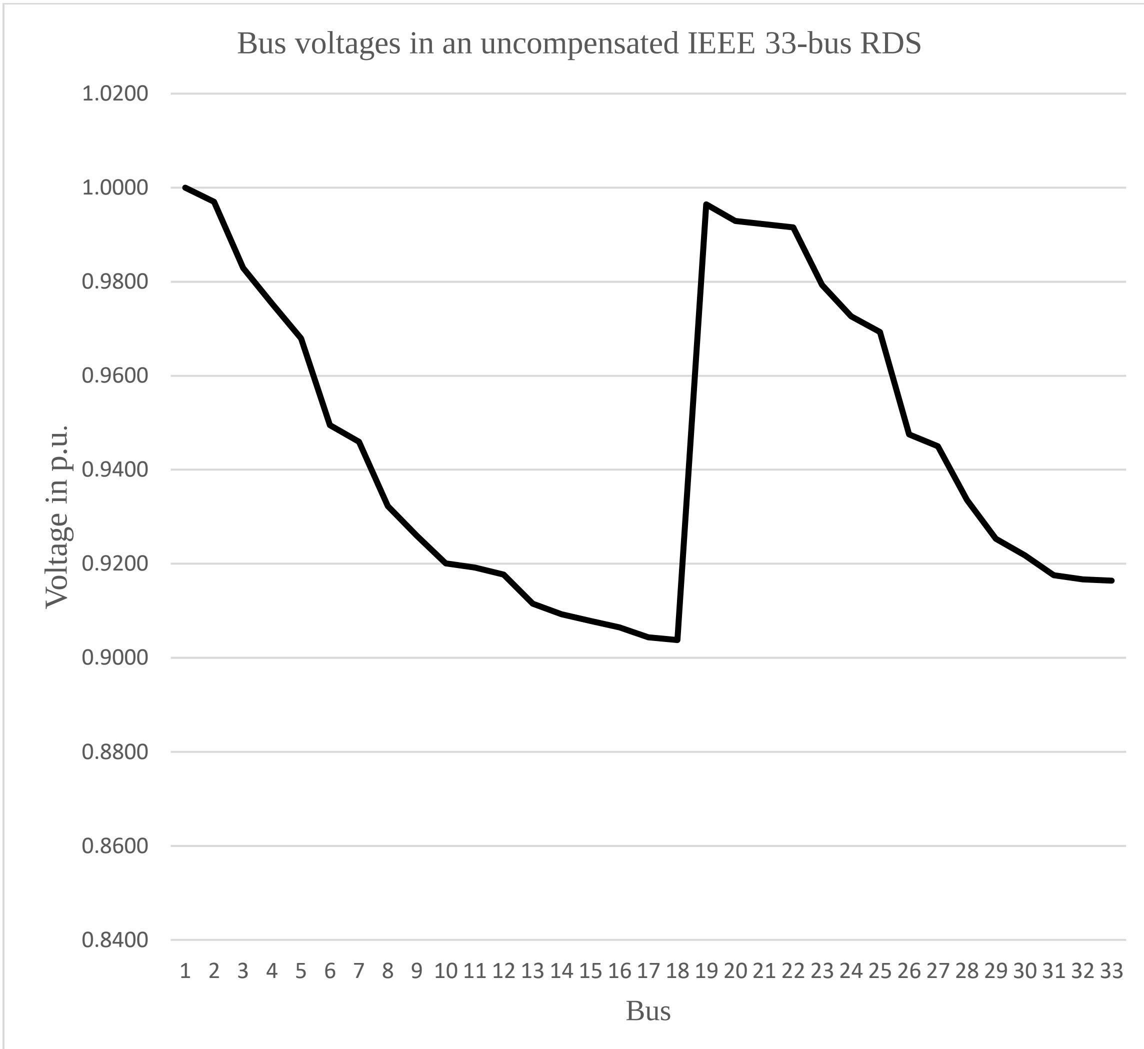


Figure 4. 1 Voltage profile of IEEE 33-bus RDS.

Figure 4.1 shows graphical representation of bus voltage at each bus in IEEE 33-bus radial distribution system before insertion of DGs. The tested network is radial in nature therefore bus voltage gradually decreases while we move gradually from source to load. The voltage values at the load buses depends on total load beyond the respective bus, line impedance and nature of loads. In an uncompensated IEEE 33-bus RDS, bus 18 experiences a significant voltage drop compared to the source. The minimum value of voltage is 11.44 kV (0.9038 P.U.) at bus 18 and the maximum voltage deviation with respect of source is 9.64%.

4.1.2 Branch real power loss in an uncompensated IEEE 33 bus RDS

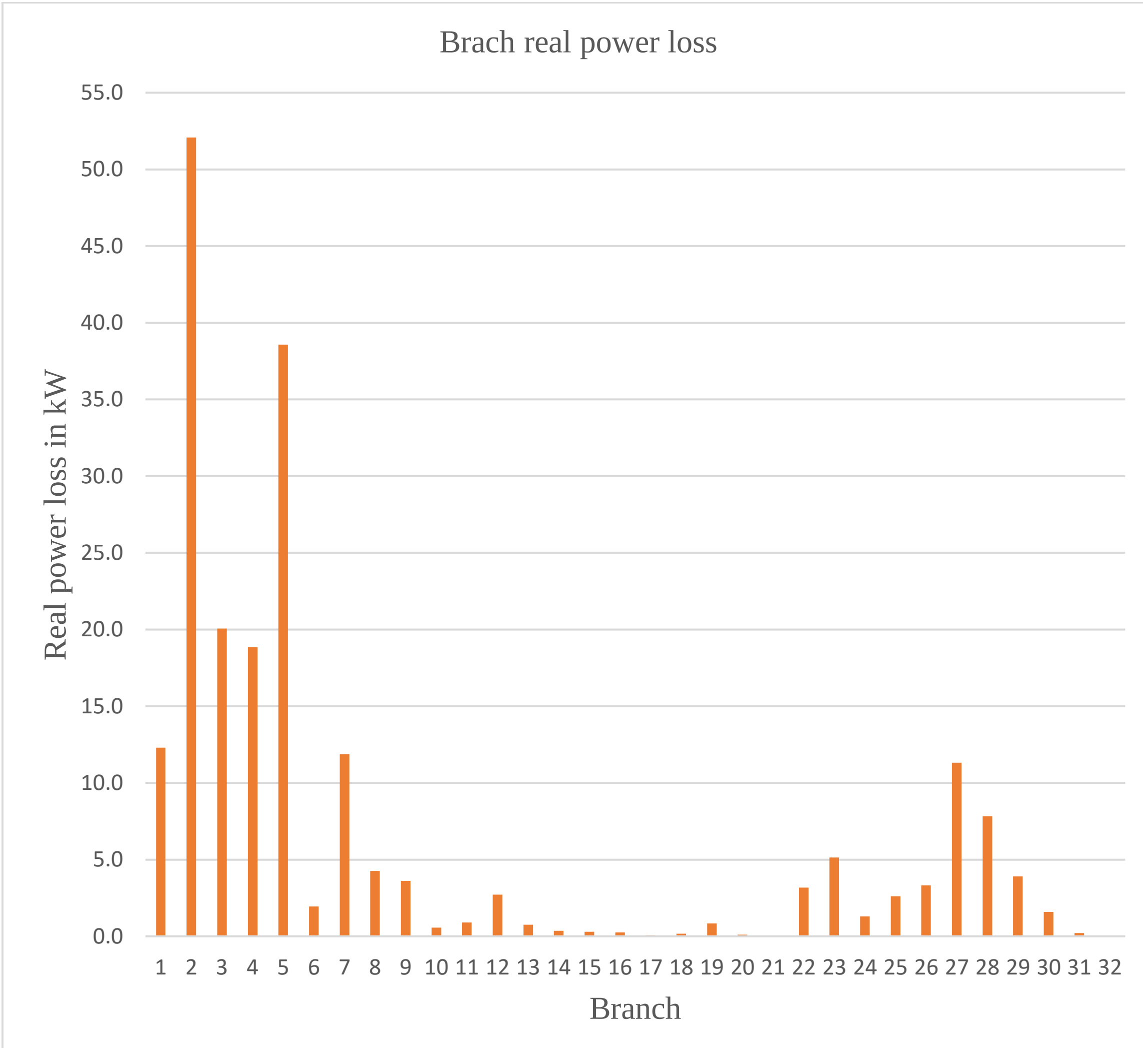


Figure 4. 2 Branch real power loss in IEEE 33-bus RDS.

Figure 4.2 illustrates the bar representation depicting the individual branch active power losses in the IEEE 33-bus radial distribution system (RDS). Active power loss in an electric network depends on current and its line parameter. From the above figure we can observe that the maximum power loss occurs in branch 2 i.e. 52.08 kW. The total active power loss of an uncompensated network is 210.99 kW.

4.1.3 Branch reactive power loss in an uncompensated IEEE 33-bus RDS.

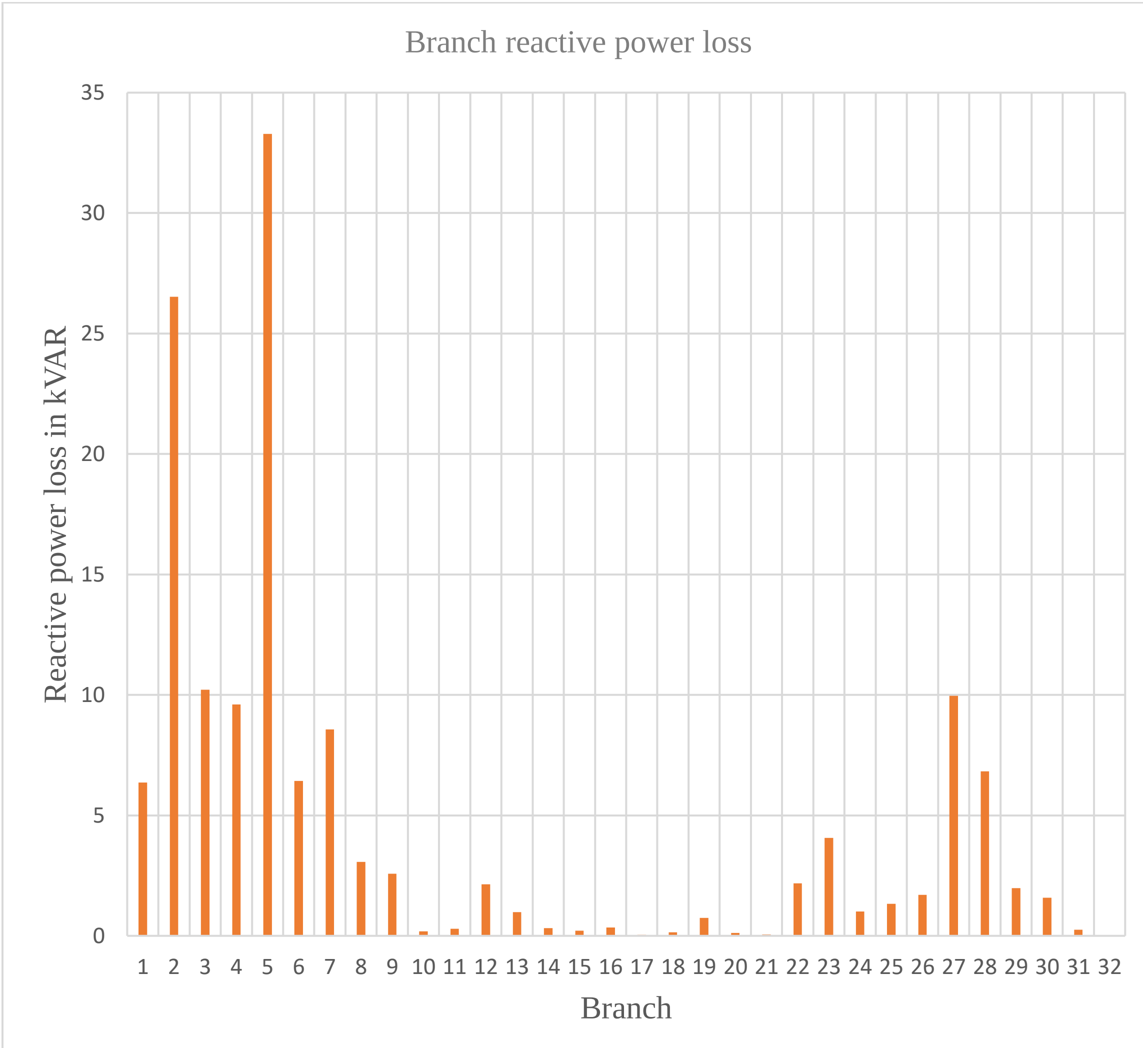


Figure 4. 3 Branch reactive power loss in IEEE 33-bus RDS.

Figure 4.3 displays a bar representation of the reactive power losses for all branches in the IEEE 33-bus radial distribution system (RDS). The figure highlights that branch 5 has the highest reactive power loss, specifically 33.29 kVAR. Additionally, the cumulative reactive power loss in an uncompensated network is measured to be 143.13 kVAR.

4.1.4 Total power loss in an uncompensated IEEE 33-bus RDS.

The active and reactive power loss in an uncompensated IEEE 33 bus RDS is 210.986 kW and 143.127 kVAR respectively. Therefore total power loss due to real and reactive current component is 254.951 kVA.

4.1.5 Optimum location of DG using LSF.

Similarly, the algorithm described in Chapter 3 is applied to the same system, the loss sensitivity factors ($\partial Plineloss/\delta Qeff$) are calculated from the base case load flow and the values are arranged in descending order for all the lines of the given system.

Bus Location	Bus Voltage	Active PL	Reactive. PL	LSF	V_{norm}	flag
6	0.94947	0.0003857	0.0003329	0.01678	0.99944	1
28	0.93353468	0.0001131	9.97E-05	0.01365	0.98267	1
3	0.98288266	0.0005208	0.0002652	0.01325	1.03461	0
29	0.92531517	7.84E-05	6.83E-05	0.01031	0.97402	1
8	0.93229014	0.0001187	8.57E-05	0.01007	0.98136	1
5	0.96794732	0.0001885	9.60E-05	0.00766	1.01889	0
4	0.97537334	0.0002005	0.0001021	0.00763	1.02671	0
30	0.92175715	3.90E-05	1.99E-05	0.00604	0.97027	1
24	0.97262526	5.14E-05	4.06E-05	0.00474	1.02382	0
9	0.92595780	4.27E-05	3.06E-05	0.00465	0.97469	1
13	0.91154206	2.72E-05	2.14E-05	0.00452	0.95952	1
10	0.92010089	3.62E-05	2.58E-05	0.00445	0.96853	1
27	0.94497621	3.33E-05	1.70E-05	0.00367	0.99471	1
31	0.91759526	1.59E-05	1.58E-05	0.00303	0.96589	1
26	0.94754040	2.60E-05	1.33E-05	0.00268	0.99741	1
2	0.99701454	0.000123	6.36E-05	0.00266	1.04949	0
23	0.97929675	3.18E-05	2.17E-05	0.00264	1.03084	0
25	0.96930010	1.29E-05	1.01E-05	0.00238	1.02032	0
20	0.99290851	8.32E-06	7.50E-06	0.00228	1.04517	0
14	0.90925218	7.44E-06	9.80E-06	0.00139	0.95711	1
7	0.94594538	1.95E-05	6.43E-05	0.00133	0.99573	1
12	0.91771740	8.99E-06	2.97E-06	0.00133	0.96602	1
17	0.90439553	2.57E-06	3.43E-06	0.00118	0.952	1
16	0.90644352	2.87E-06	2.10E-06	0.00091	0.95415	1
15	0.90782543	3.64E-06	3.24E-06	0.00081	0.95561	1
11	0.91923218	5.65E-06	1.87E-06	0.00078	0.96761	1
32	0.91667969	2.13E-06	2.49E-06	0.00065	0.96493	1
18	0.90378225	5.42E-07	4.25E-07	0.00045	0.95135	1
21	0.992204	1.01E-06	1.18E-06	0.00042	1.04443	0
22	0.99156657	4.36E-07	5.77E-07	0.00036	1.04375	0
19	0.99648617	1.61E-06	1.54E-06	0.00033	1.04893	0
33	0.91639599	1.32E-07	2.05E-07	0.0002	0.96463	1

Table 4.1 Arrangement of buses in descending LSF

1.6 Optimizing DG Sizing (0.85 lagging p.f.) for Buses in IEEE 33-Bus RDS.

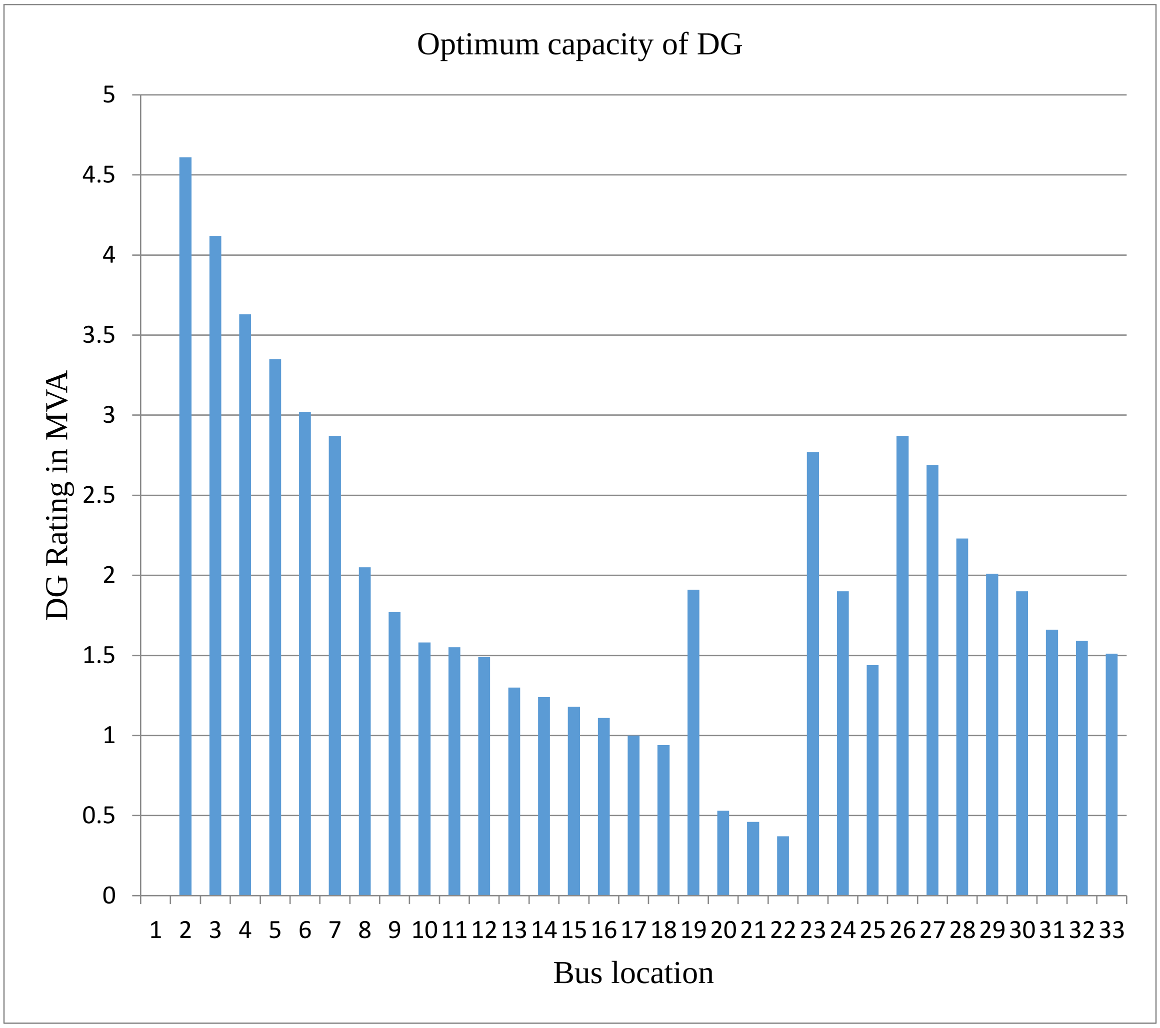


Figure 4. 4 Optimum size of DG (0.85 lagging p.f.) in various bus location.

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Figure 4.4 shows the bar representation of optimal DG Size at 0.85 lagging power factor at various bus location for IEEE 33-Bus System. From the figure, it can be inferred that the DG size does not exhibit a consistent pattern and is not dependent on the location of the bus. The minimum and maximum size of DG varies from 0.37 MVA (at bus 22) to 4.61 MVA (at bus 2). The load data of test system is modified accounting single DG placement and calculation of losses are performed.

4.1.7 Total real power loss after optimum size DG (0.85 lagging p.f.) placement in each bus.

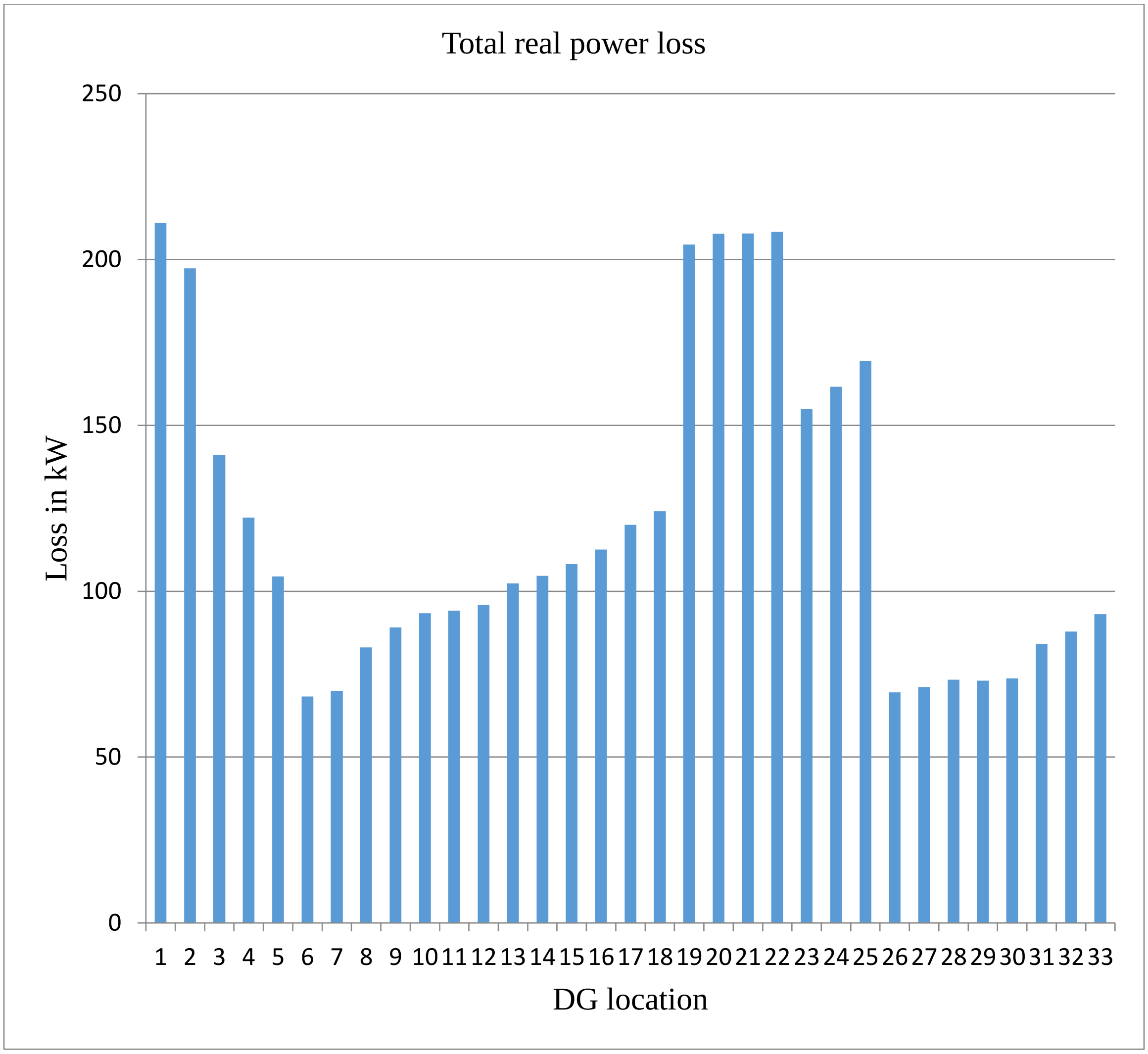

Figure 4. 5 Total real power loss after placement of optimum size DG (0.85 lagging p.f.)

Figure 4.5 presents a bar representation illustrating the total real power loss of the system when optimal size distributed generations (DGs) are inserted at each bus of the IEEE 33-bus radial distribution system (RDS). The optimum size of DG with 0.85 lagging power factor in bus location 2 is 4.61 MVA. After insertion optimum size DG in bus 2, total real power loss of RDS is 197.31 kW. Total real power loss decreases than that of base case but it's not minimum. Hence, it is imperative to select the size and location of DG units appropriately. The least value of real power loss is 68.21 kW for when DG is placed at bus 6. It is clearly seen form the bar representation the optimal location is bus 6 and optimum size of DG is 3.02 MVA for occurrence of minimum real power loss in a system.

4.1.8 Total reactive power loss after optimum size DG (0.85 lagging power factor) placement in each bus.

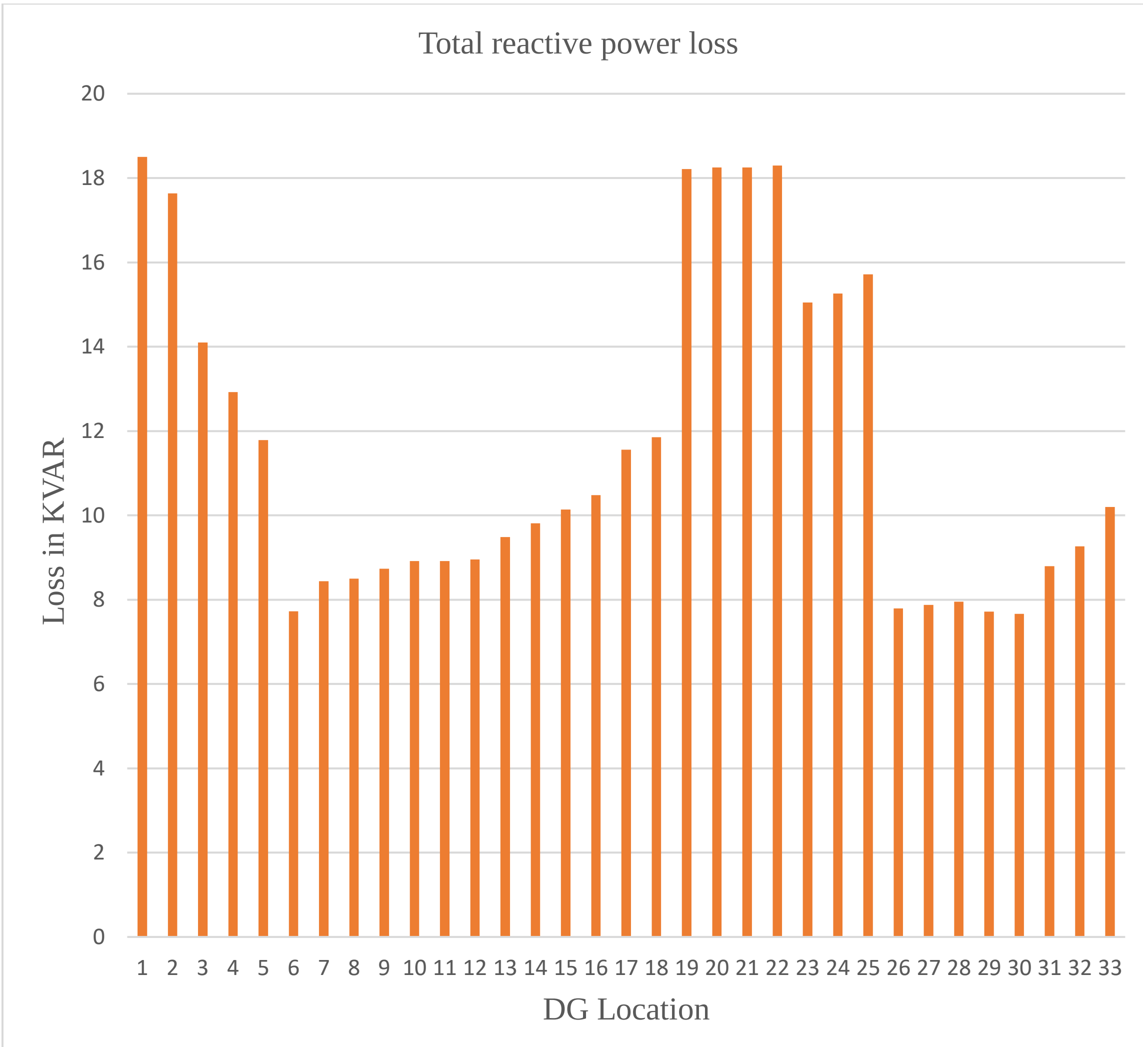

Figure 4. 6 Reactive power loss after placement of optimum size DG (0.85 lagging p.f.)

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Figure 4.6 show the bar representation of system total reactive power loss with optimal size DGs placed at each bus in IEEE 33-bus RDS. While we insert the optimum value of DG of capacity 4.61 MVA in bus 2, total reactive power loss (17.64 kVAR) decreases than that of base case (18.50 kVAR) but not minimum. Hence in order to obtain system minimum reactive power loss and improve voltage profile, the size and location of DGs must be selected carefully. The least value of reactive power loss is 7.72 kVA for optimum size DG placement at bus 6. It is clearly seen form the bar representation the optimal location is bus 6 and optimum size of DG is 3.02 MVA.

4.1.9 Total power loss before and after placement of optimum size DG (0.85 lagging power factor) in each bus.

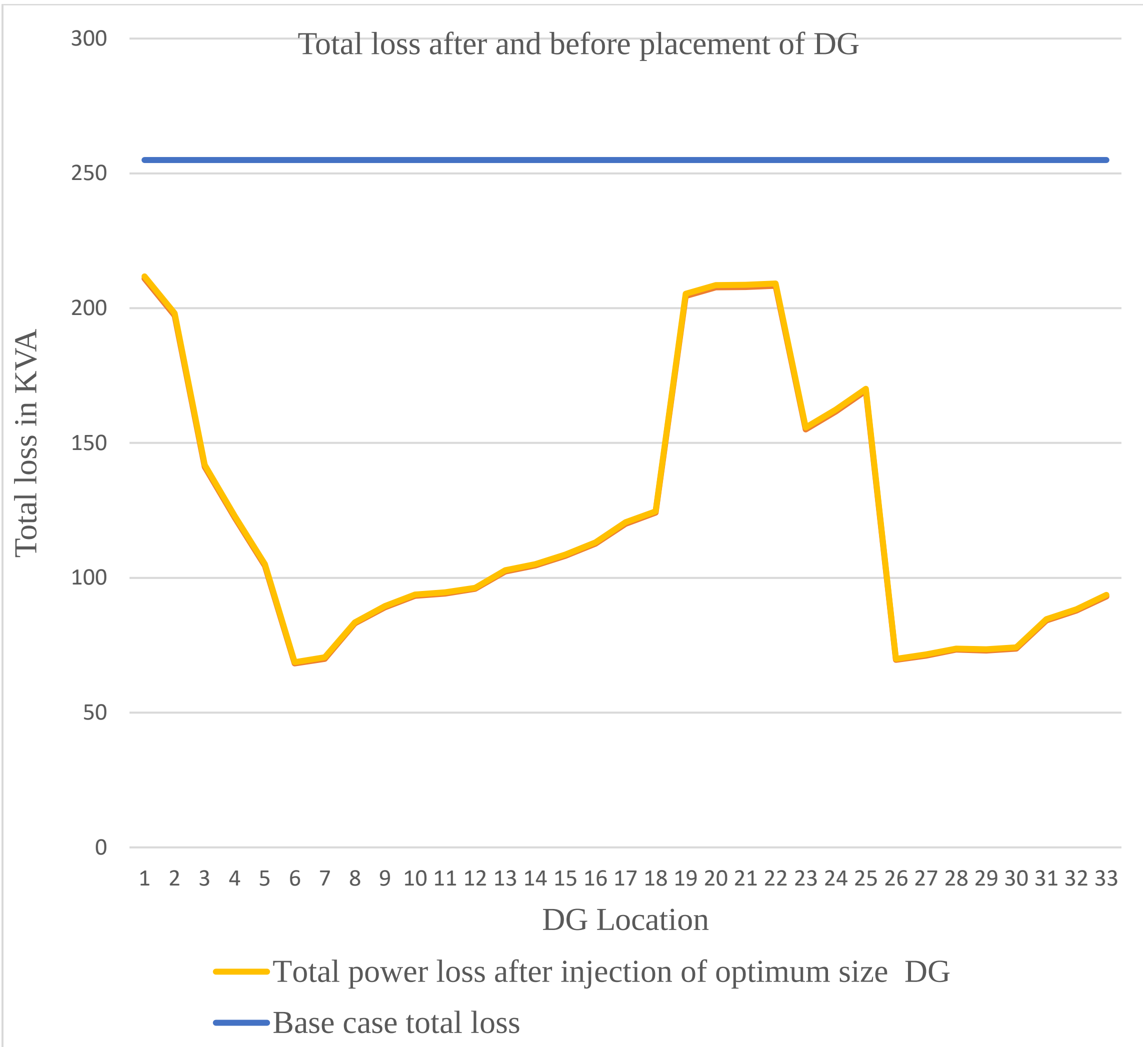

Figure 4. 7 Total power loss before and after insertion of DG (0.85 lagging p.f.).

Figure 4.7 displays a graphical representation depicting the system's total power loss when optimal size distributed generations (DGs) are placed at each bus in the IEEE 33-bus radial distribution system (RDS). Blue line shows the total power loss in an uncompensated network. Total power loss after the placement of optimum size DG in various bus location is shown by yellow line. The lowest value of total power loss in the system, approximately 68.61 kVA, is observed when an optimal size distributed generation (DG) is placed at bus 6. It is clearly seen form the bar representation the optimal location is bus 6 and optimum size of DG is 3.02 MVA and minimum total power loss obtain is 68.61 kVA.

4.1.10 Comparison of voltage level before and after compensation (3.02 MVA DG at 0.85 lagging power factor at bus 6) in IEEE 33-bus RDS.

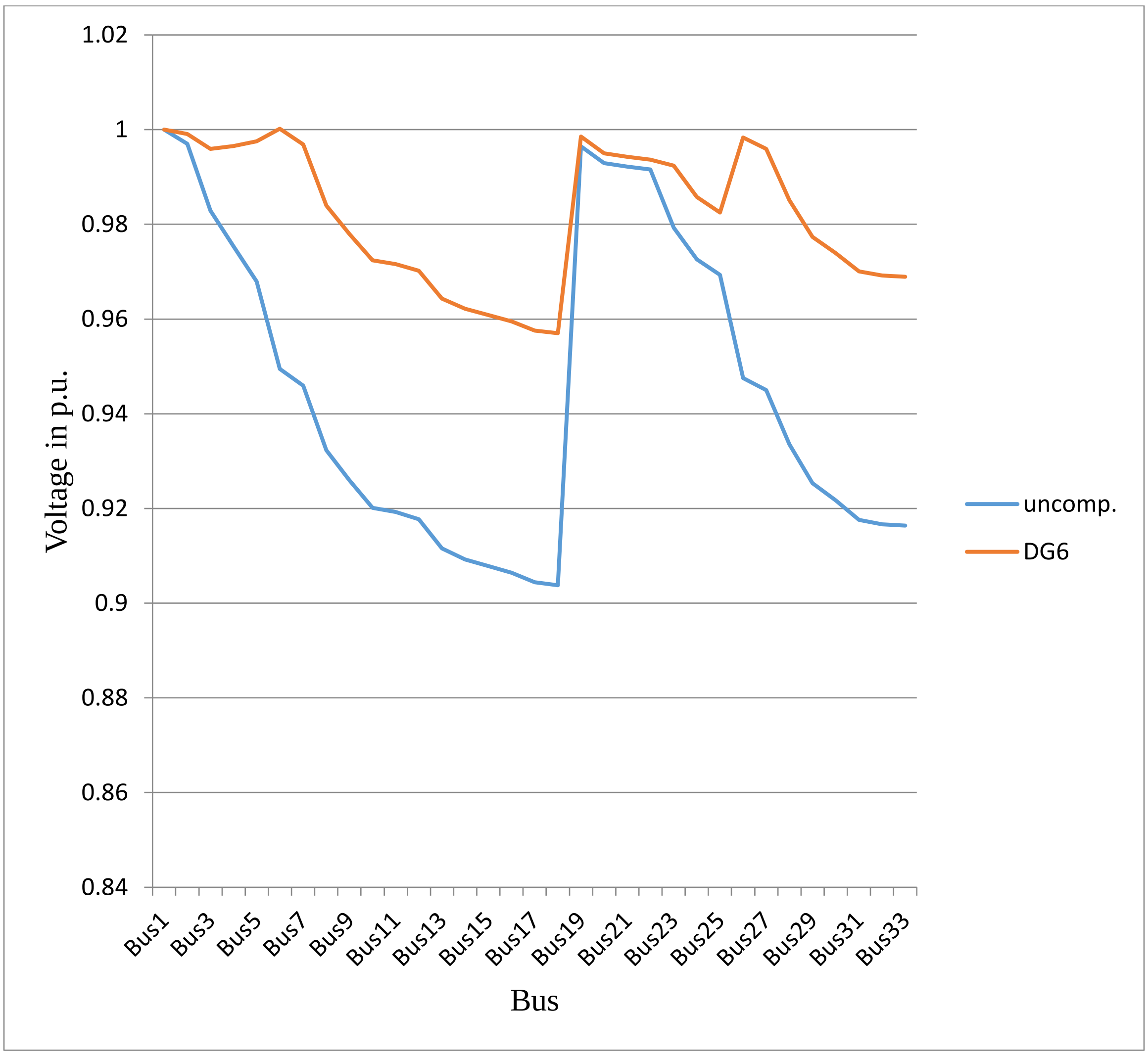

Figure 4. 8 Bus voltage profile after and before insertion of DG at bus 6.

Figure 4.8 shows the graphical representation of voltages before and after DG placement in bus 6. The voltage profile is enhanced, as evidenced by the difference between the orange and blue lines. Before placement of DG, the lowest voltage is at bus 18 i.e. 11.44 kV (0.9037 P.U.) but after the placement of DG it has been considerably increased to 12.12 kV (0.957 p.u.).

IEEE 33-bus RDS	Case	V_{min} (p.u)	Bus	P_{loss} (kW)	Q_{loss} (kVAR)	S_{loss} (kVA)	DG Size(MVA)	Location
	Base Case	0.9038	18	210.95	143.12	254.95		
	DG placement	0.957	18	68.21	7.72	68.61	3.02	6

Table 4.2 Comparison of results before and after insertion of DG (0.85 lagging p.f.) in IEEE 33-bus RDS.

4.2 Case II – 33 kV Kohalpur-Surkhet Primary Distribution System (KSPDS).

After successfully validating the power loss expression using the IEEE 33-bus Radial Distribution System, the MATLAB program was executed on the 33 kV Kohalpur-Surkhet Primary Distribution System (KSPDS) to determine the optimal size and location of distributed generation (DG) for various power factors. The algorithm described in the previous sections was tested on a practical 23-bus radial distribution system (RDS).The KSPDS has a total length of 91.4 km and consists of 23 buses, including 3 laterals. The total load observed in the system was found to be 8948 kW (real power) and 2271 kVAR (reactive power). The load data and line data for the 23-bus radial distribution system can be found in Annex C.All calculations in the program were performed using the per unit system. The base voltage and base MVA were assumed to be 33 kV and 100 MVA, respectively.

Base current $=\frac{\text{Base MVA}}{\sqrt{3}*\text{Base KV}} = \frac{100\text{ MVA}}{\sqrt{3}*33\text{ KV}} = 174.95$ A

Base impedance $=\frac{\text{Base KV}^2}{\text{Base MVA}} = \frac{33^2}{100} = 10.89\ \Omega$

4.2.1 Optimum placement of DG with 0.85 lagging power factor.

The distributed generations (DGs) capable of delivering real as well reactive power to the system falls under this category. In this research it is named as type-3 DG. The generating units utilized in this context, such as cogeneration systems and gas turbines, are typically based on synchronous machines. These units have a power factor range between 0 and 1.

4.2.1.1 Voltage at different bus in an uncompensated KSPDS.

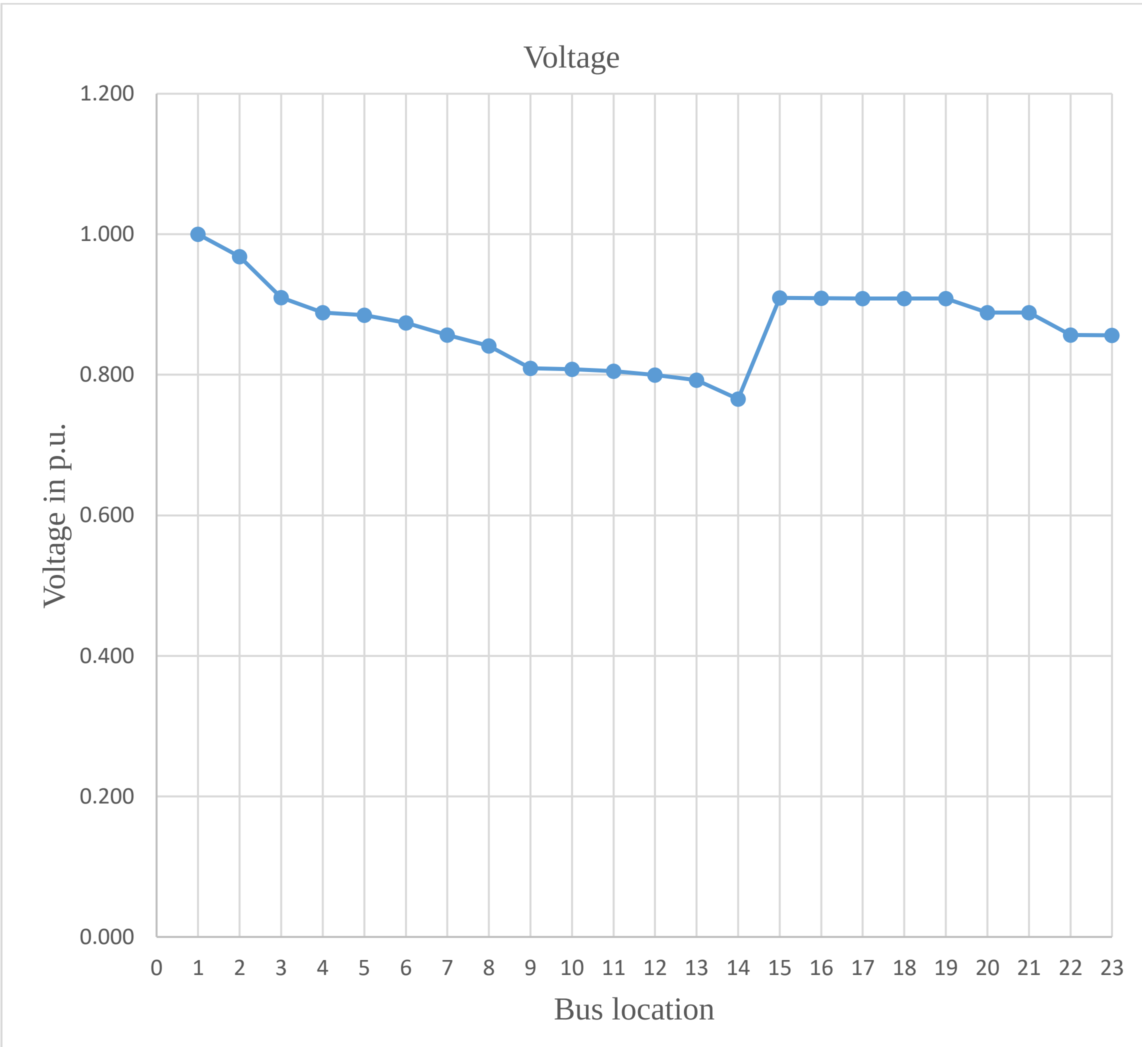

Figure 4. 9 Voltage profile of KSPDS.

Figure 4.9 shows graphical representation of bus voltage at each bus in practical Kohalpur-Surkhet primary distribution feeder before insertion of DGs. The tested network is radial in nature having three laterals and 23 bus, therefore bus voltage gradually decreases while we move gradually from source to load. The voltage values at the load buses depends on total load beyond the respective bus, line impedance and nature of loads. In an uncompensated KSPDS, bus 14 experiences a significant voltage drop compared to the source. The minimum value of voltage is 25.27 kV (0.766 P.U.) at bus 14 and the maximum voltage deviation with respect of source is 23.4%.

4.2.1.2 Branch real power loss in an uncompensated KSPDS.

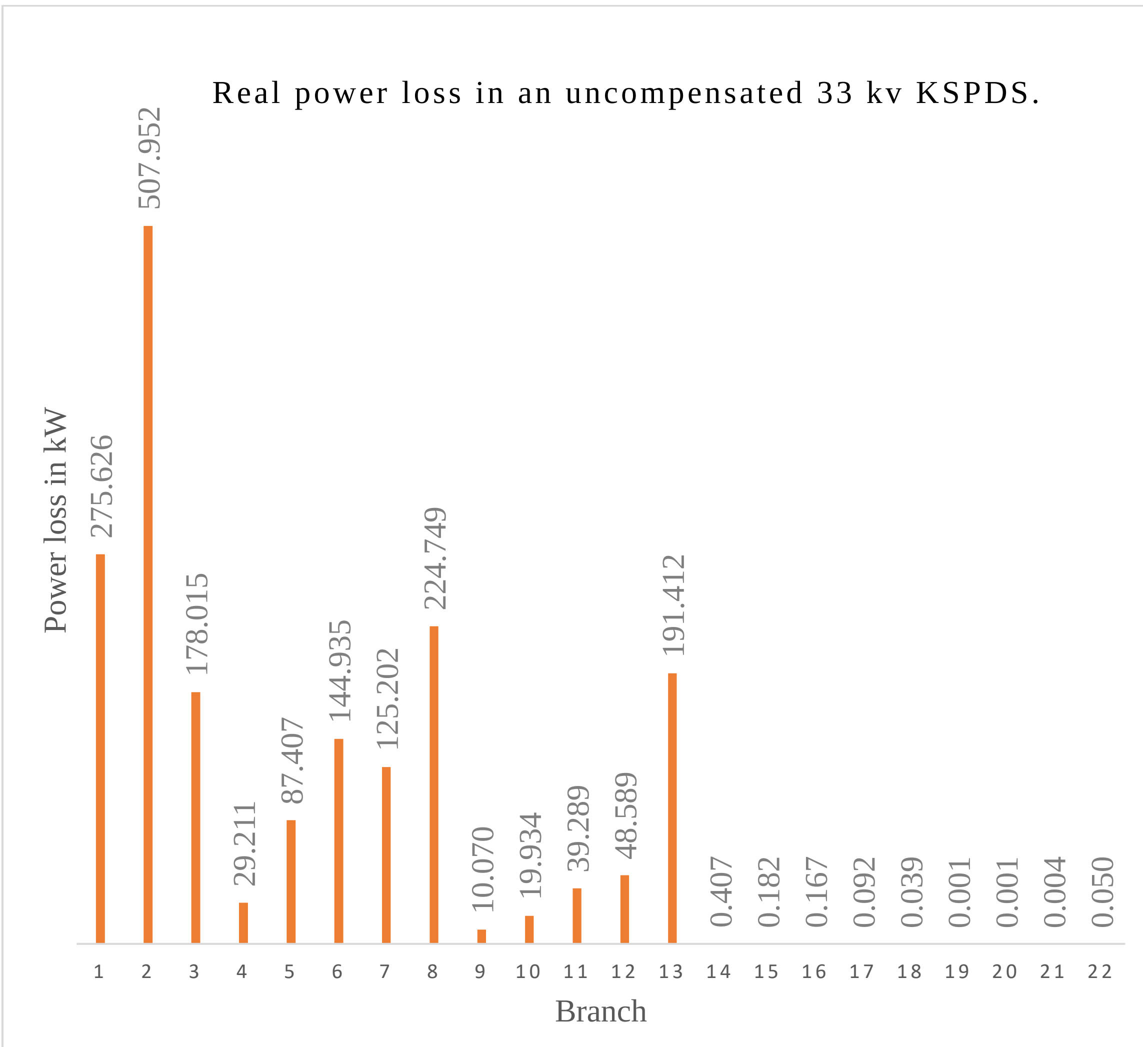

Figure 4. 10 Branch real power loss of KSPDS.

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Fig. 4.10 shows the bar representation of active power loss of all the branches of Kohalpur-Surkhet 33 kV primary distribution system. Active power loss in an electric network depends on current and its line parameter. From the above figure we can observe that the maximum power loss occurs in branch 2 i.e. 507.95 kW. The total active power loss of an uncompensated network is 1883.33 kW.

4.2.1.3 Branch reactive power loss in an uncompensated KSPDS.

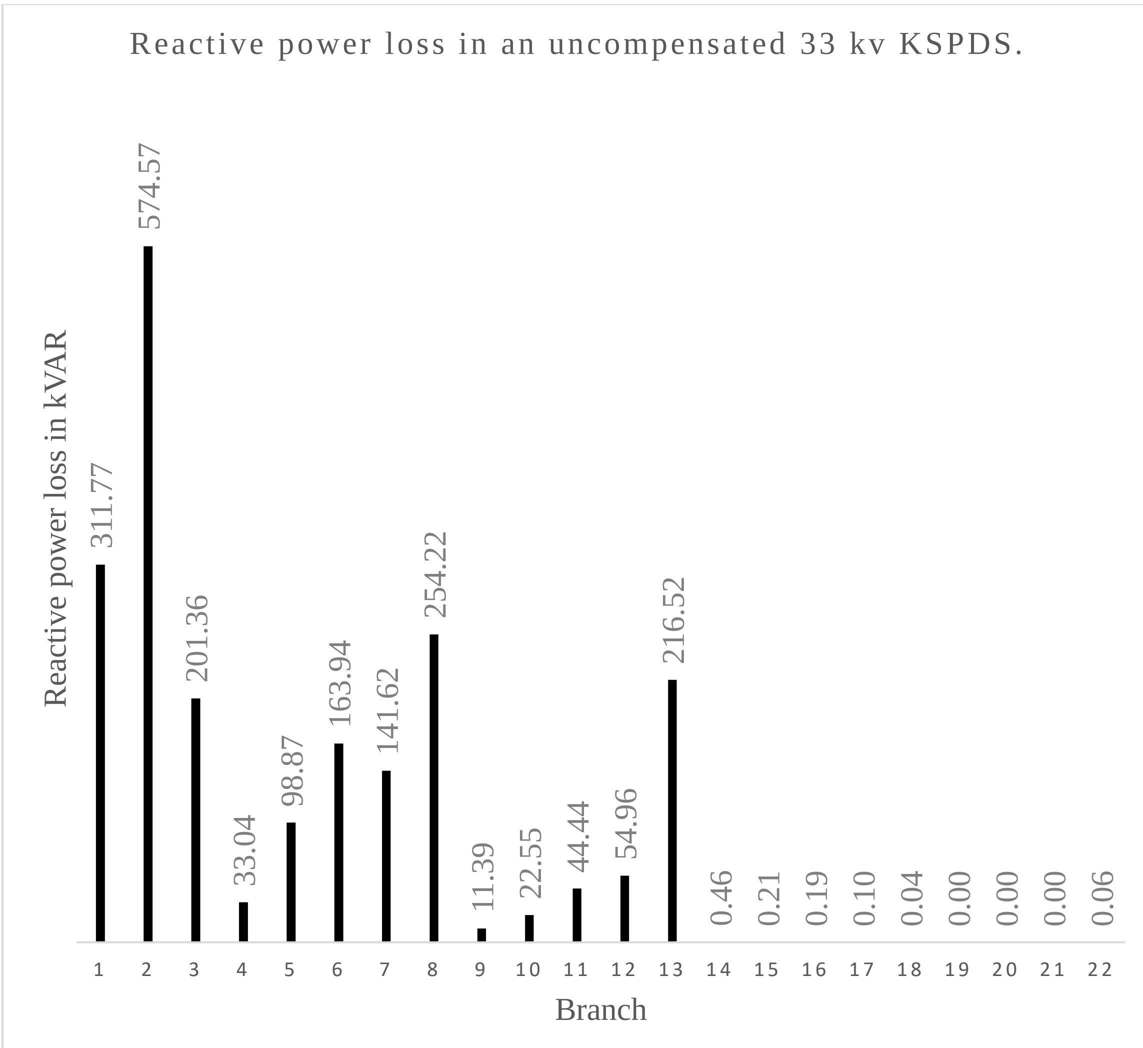

Figure 4. 11 Branch reactive power loss in KSPDS.

Figure 4.11 displays a bar representation illustrating the reactive power losses for all branches of the Kohalpur-Surkhet Primary Distribution System. From the figure, it is evident that branch 2 has the highest power loss, specifically 574.57 kVAR. Additionally, the cumulative reactive power loss in an uncompensated network is measured to be 2130.33 kVAR.

4.2.1.4 Total power loss in an uncompensated KSPDS.

The total active and reactive power loss in an uncompensated Surkhet-Kohalpur 33 kV Primary RDS is 1883.33 kW and 2130.33 kVAR respectively. Therefore total power loss due to real and reactive current component is 2843.27 kVA.

4.2.1.5 Determination of optimum size of DG (0.85 lagging power factor) for each buses in KSPDS.

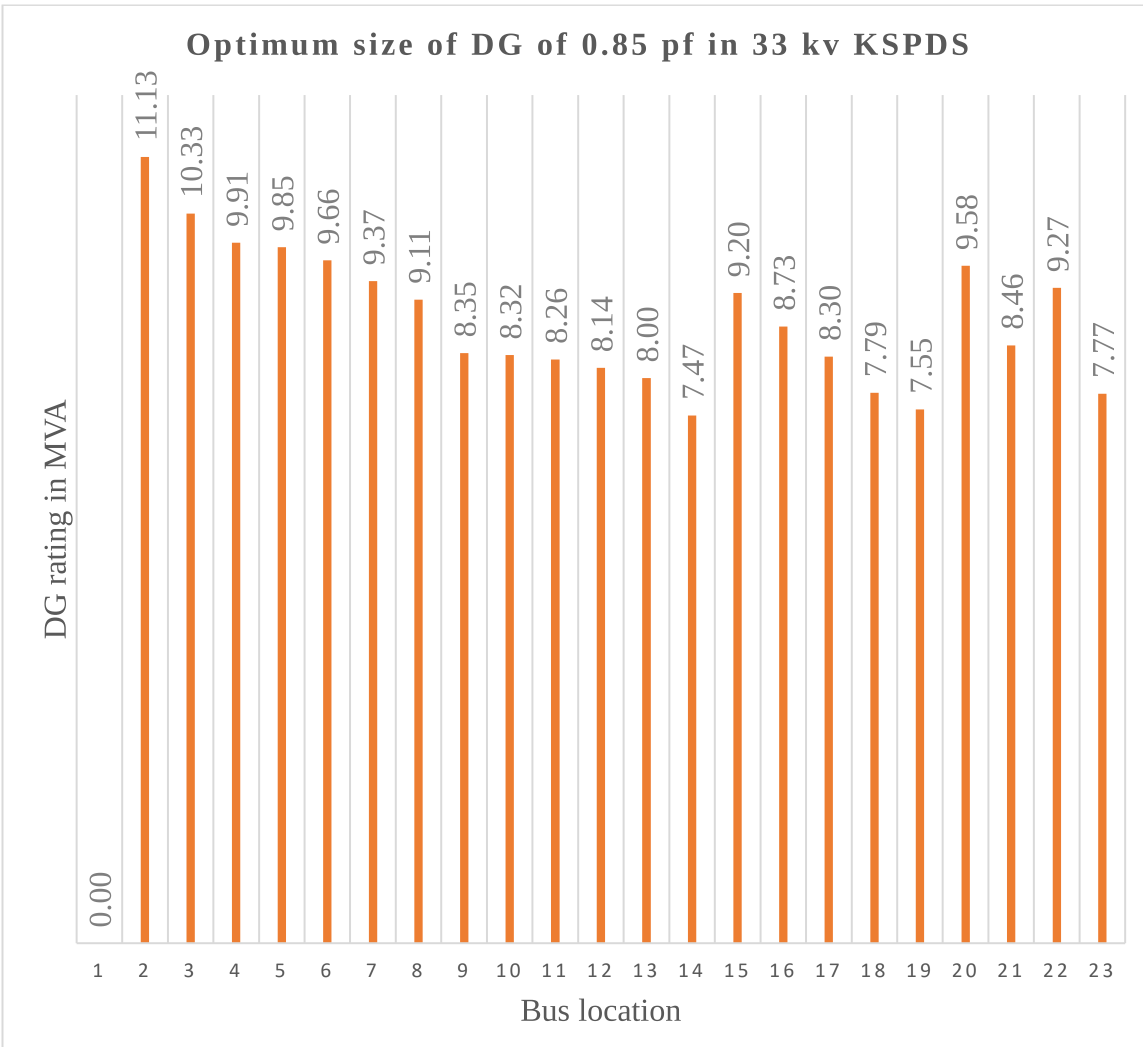

Figure 4. 12 Optimum size of DG (0.85 lagging p.f.) in KSPDS.

Figure 4.12 presents a bar representation illustrating the optimal sizes of distributed generations (DGs) at all buses for the Kohalpur-Surkhet Primary Distribution System. The optimal DG sizes range from 7.47 MVA to 11.13 MVA. From the figure, it can be inferred that the DG sizes do not exhibit a consistent pattern and are not dependent on the location of the bus (whether it is on the main line or lateral line).

4.2.1.6 Total real power loss after the placement of optimum size DG (0.85 lagging power factor) in each bus.

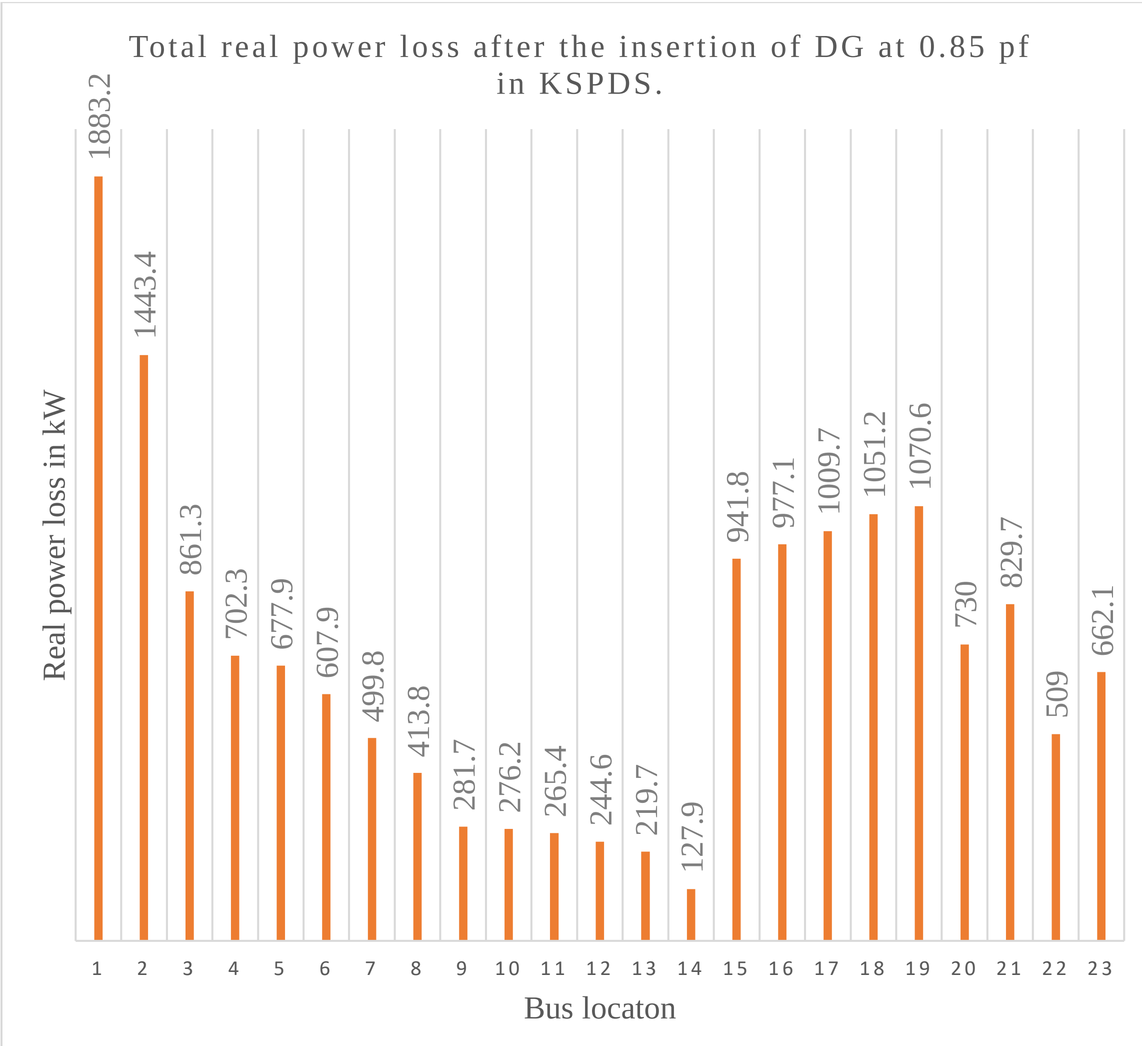

Figure 4. 13 Real power loss after the placement of optimum size DG in practical feeder.

Figure 4.13 displays a bar representation illustrating the system's total real power loss when optimal size distributed generations (DGs) are placed at each bus in the Kohalpur-Surkhet Primary Distribution System. From the figure, it is evident that the lowest power loss value is approximately 127.9 kW, which occurs when a 7.47 MVA DG is placed optimally at bus 14. The bar representation clearly indicates that bus 14 is the optimal location and the optimum size of the DG is 7.47 MVA

4.2.1.7 Total Reactive power loss after the placement of optimum size DG (0.85 lagging power factor) in each bus.

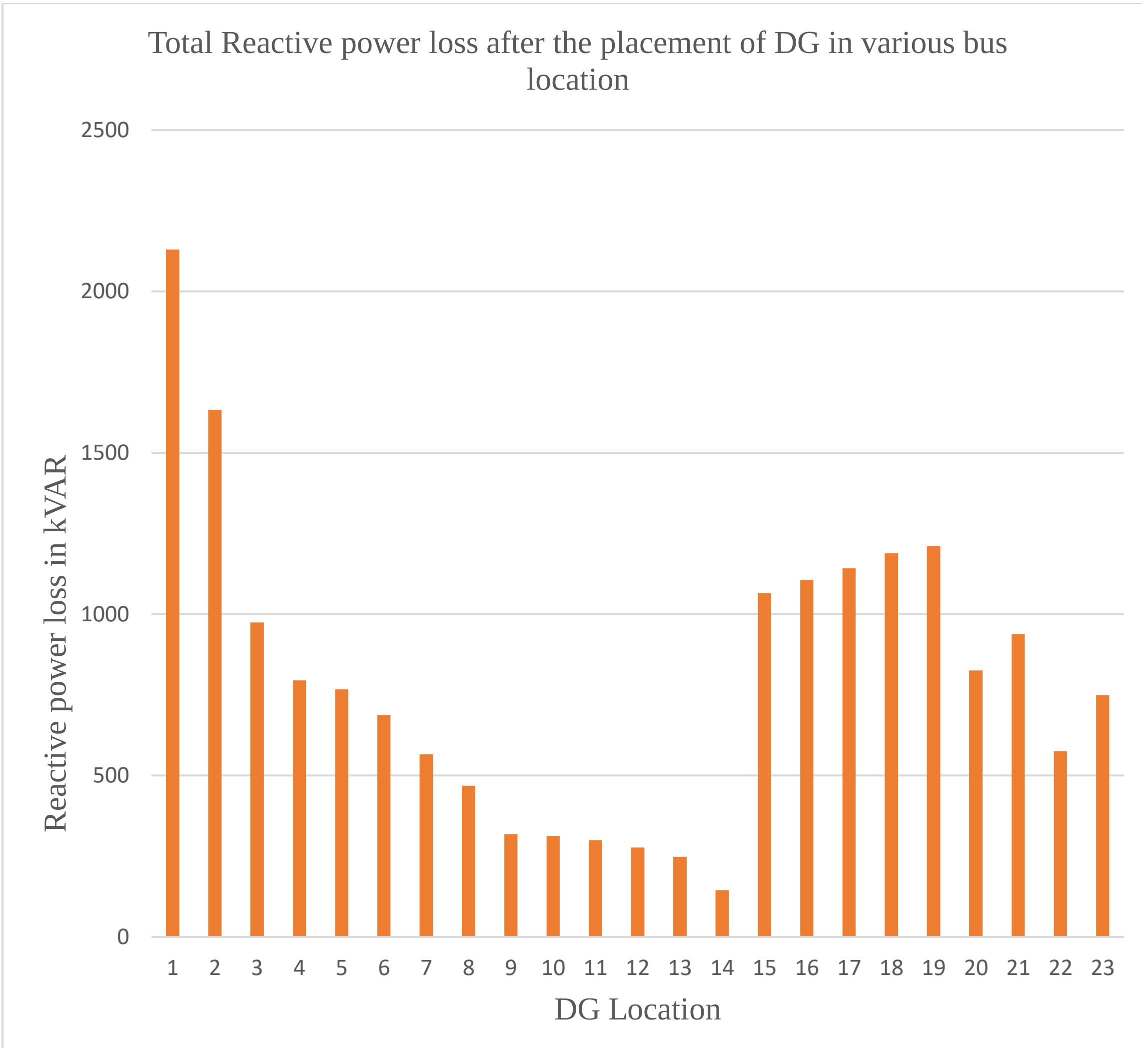

Figure 4. 14 Reactive power loss after DG placement in KSPDS.

Figure 4.14 presents a bar representation depicting the system's total reactive power loss when optimal size distributed generations (DGs) are placed at each bus in the Kohalpur-Surkhet Primary Distribution System. The figure indicates that the lowest reactive power loss value is approximately 144.6 kVAR, which occurs when a 7.47 MVA

DG is optimally placed at bus 14. It is evident from the bar representation that bus 14 is the optimal location for DG placement, and the optimum size of the DG is 7.47 MVA.

4.2.1.8 Total power loss after the placement of optimum size DG (0.85 lagging power factor) in each bus.

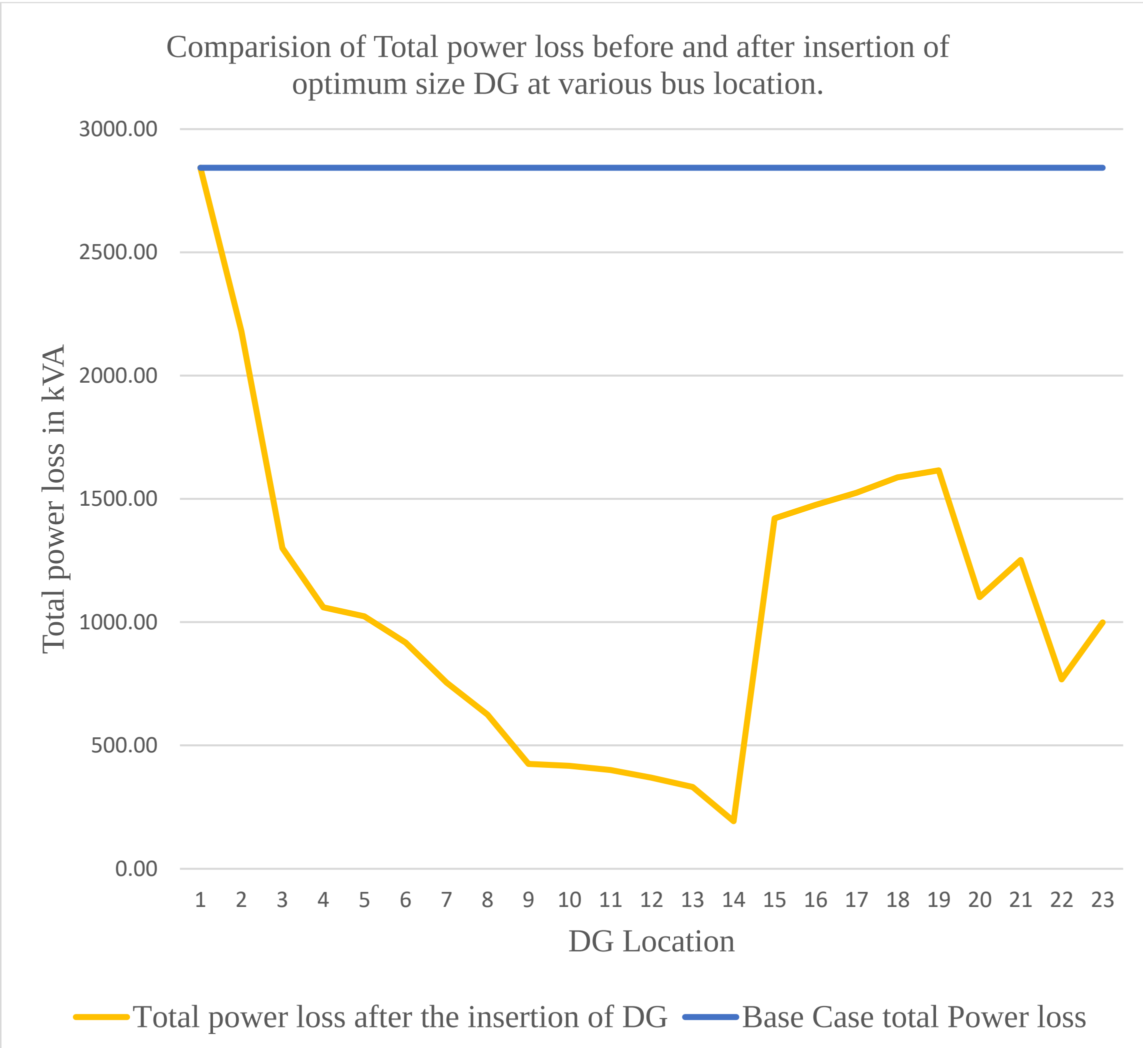

Figure 4. 15 Total power loss after the insertion of DG 0.85 p.f. in various bus location.

Figure 4.15 show the graphical representation of 33 kV practical primary distribution system total power loss with DG of optimum size is placed at each bus. The least value of total loss obtained is 193.05 kVA for optimum size DG placement at bus 14. It is clearly seen form the bar representation the optimal location is bus 14 and optimum size of DG is 7.47MVA.

4.2.1.9 Comparison of voltage level before and after compensation (7.47 MVA DG at 0.85 lagging power factor at bus 14) in practical 33 kV primary distribution system.

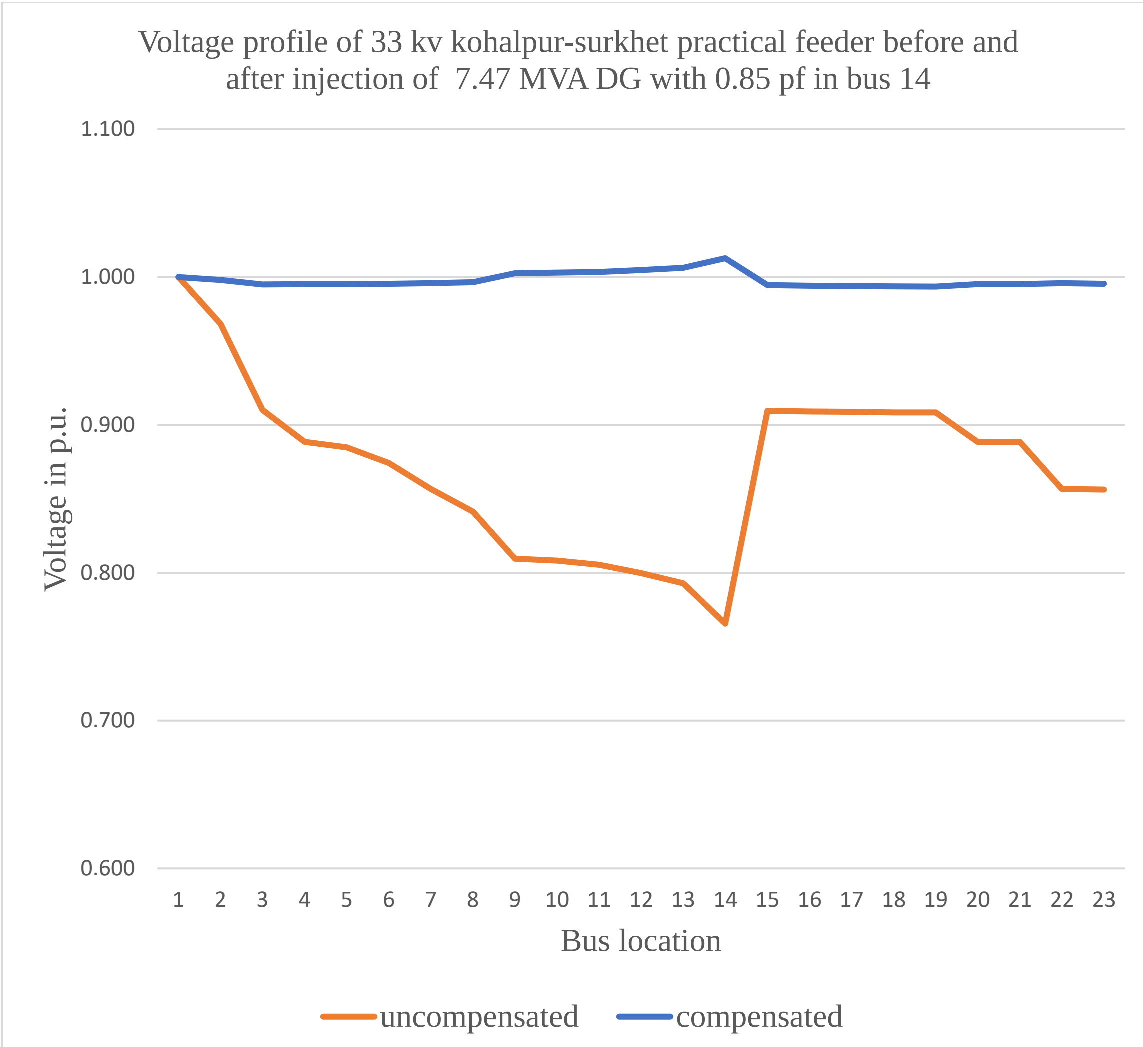

Figure 4. 16 Voltage profile before and after placement of DG in bus 14.

Figure 4.16 illustrates a graphical representation of voltages before and after the placement of a DG at bus 14. The voltage profile demonstrates an improvement, which can be observed as the difference between the orange and blue lines. Prior to the DG placement, the lowest voltage is recorded at bus 14, measuring 25.27 kV (0.766 per unit). However, after the insertion of a 7.47 MVA DG with a power factor of 0.85 lagging, the lowest voltage in the compensated network is 32.785 kV (0.993 per unit), which occurs at bus 19. The maximum voltage deviation in the compensated network is reported to be 0.7%.

Kohalpur-Surkhet primary distribution system		
Case	Base Case	DG with 0.85 power factor
V_{min} (p.u.)	0.766	0.993
Voltage in kV	25.27	32.77
V_{min} Bus location	14	19
P_{loss} (kW)	1863.33	127.91
Q_{loss} (kVAR)	2130.33	144.6
S_{loss} (kVA)	2843.27	193.05
DG Size(MVA)		7.47
DG Location		14

Table 4.3 Comparison of results before and after insertion of DG (0.85 lagging p.f.) in Kohalpur-Surkhet primary distribution system

4.2.2 Optimum placement of DG having unity power factor

The distributed generations (DGs) capable of delivering real power only to the system falls under this category. In this research it is named as type-1 DG and has unity power factor. Photovoltaic, fuel cells, micro turbines which are integrated to the main grid with the help of converters/inverters are good example of type-1 DG.

4.2.2.1 Determination of optimum size of DG at Unity power factor for each buses in Surkhet-Kohalpur 33 kV Primary Distribution System.

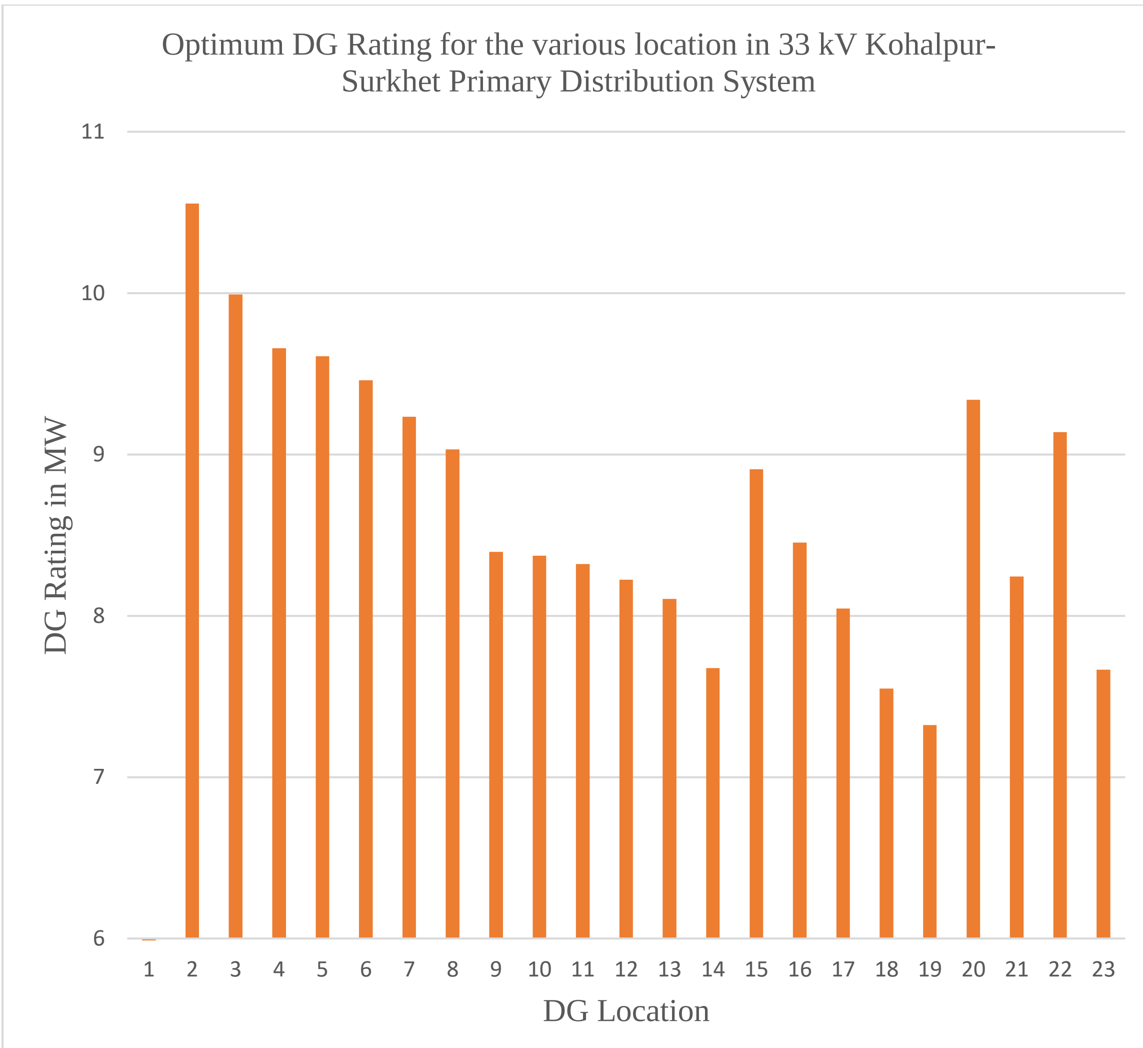

Figure 4. 17 Optimal size of DG (unity p.f.) in KSRDS.

Figure 4.17 presents a bar representation depicting the optimal sizes of distributed generations (DGs) at all buses for the practical Kohalpur-Surkhet Primary Distribution

System. The optimal DG sizes range from 7.32 MW (at bus location 19) to 10.56 MW (at bus location 2). From the figure, it can be concluded that the DG sizes do not follow a regular pattern and are not dependent on the location of the bus.

4.2.2.2 Total real power loss after the placement of optimum size DG (unity power factor) in each bus.

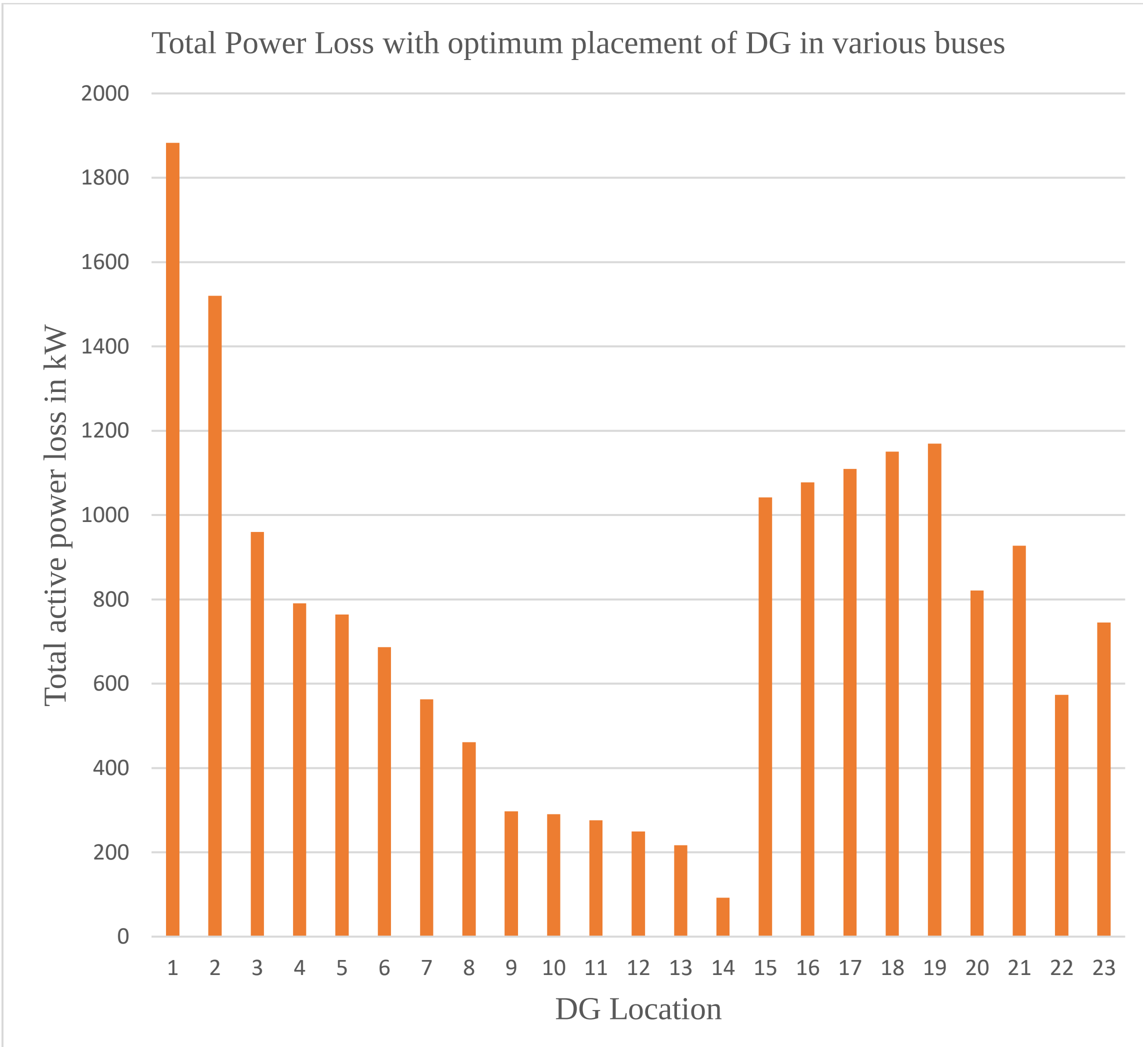

Figure 4. 18 Real power loss after placement of unity p.f. DG.

Figure 4.18 illustrates a bar representation showing the system's total real power loss when optimal size distributed generations (DGs) are placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. It is observed that despite the optimal capacity of the DG at bus location 19 being 7.32 MW, the total power loss after compensation results in an active power loss of 1169.3 kW, which is higher than the loss incurred when a 7.68 MW DG is placed at bus location 14. The lowest power loss value is approximately 92.2 kW, and it occurs when an optimum size DG of 7.68 MW is placed at bus 14. The bar representation clearly indicates that the optimal location for DG placement is bus 14, and the optimum size of the DG is 7.68 MW.

4.2.2.3 Total Reactive power loss after the placement of optimum size DG (unity power factor) in each bus.

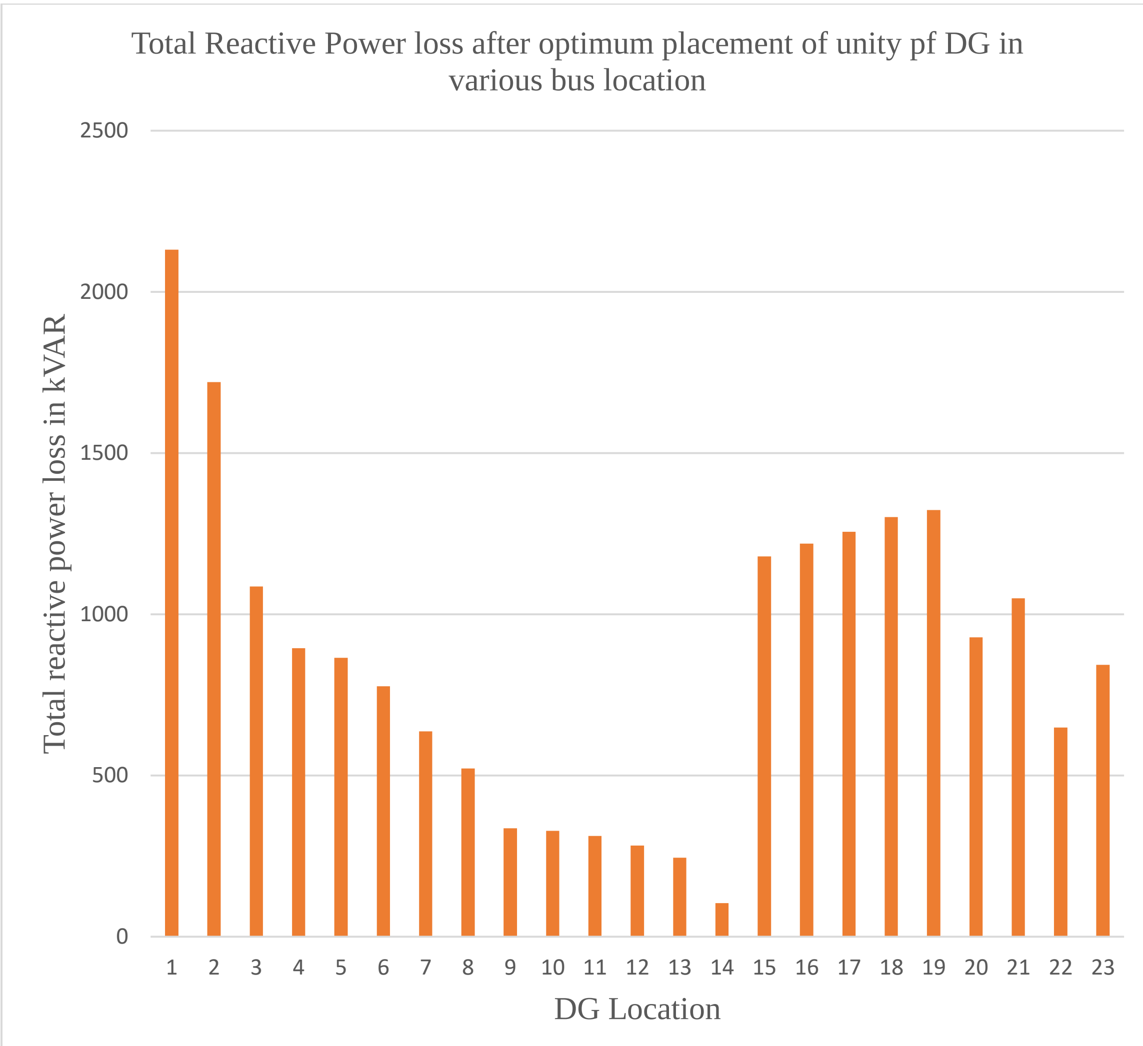

Figure 4. 19 Reactive power loss after placement of unity p.f. DG.

Figure 4.19 displays a bar representation illustrating the system's total reactive power loss when optimal size distributed generations (DGs) are placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. The bar representation indicates that the lowest reactive power loss value is approximately 104.3 kVAR, which occurs when an optimum size DG of 7.68 MW is placed at bus 14. It is evident from the bar representation that bus 14 is the optimal location for DG placement, and the optimum size of the DG is 7.68 MW.

4.2.2.4 Total power loss after the placement of optimum size DG (unity power factor) in each bus.

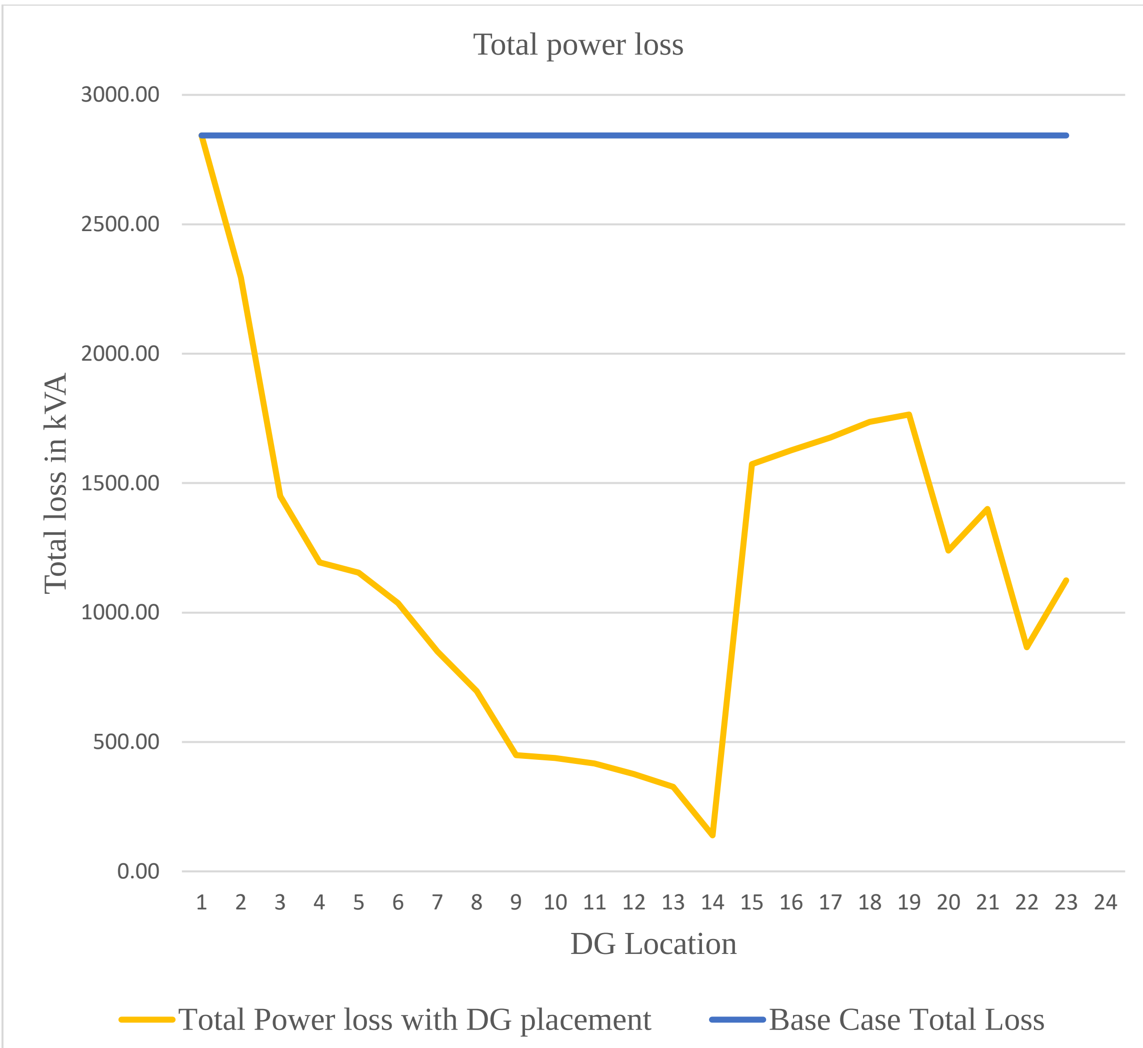

Figure 4. 20 Total power loss after placement of unity p.f. DG.

Figure 4.20 presents a bar representation illustrating the system's total power loss when optimal size distributed generations (DGs) are placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. The bar representation indicates that the lowest power loss value is 139.21 kVAR, which occurs when an optimum size DG of 7.68 MW is placed at bus 14. It is evident from the bar representation that bus 14 is the optimal location for DG placement, and the optimum size of the DG is 7.68 MW.

4.2.2.5 Comparison of voltage before and after the placement of optimum size DG (unity power factor) in each bus.

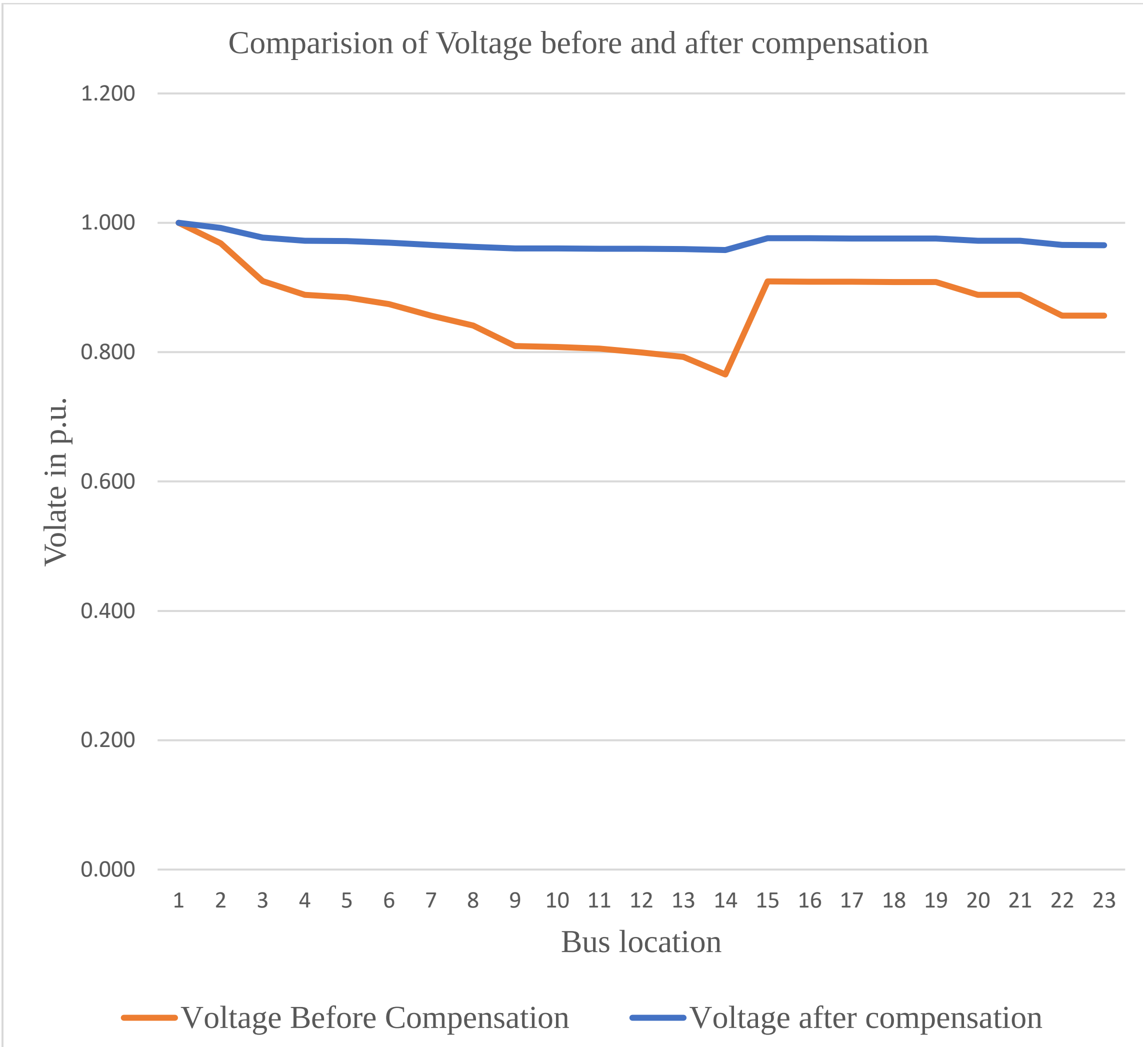

Figure 4. 21 Bus voltages before and after insertion of DG (7.68 MVA at p.f.=1) in bus 14.

Figure 4.21 depicts a graphical representation of voltages before and after the placement of a DG at bus 14 in the practical Kohalpur-Surkhet Primary Distribution System. The voltage profile demonstrates an improvement, which can be observed as the difference between the orange and blue lines. Prior to the DG placement, the lowest voltage is recorded at bus 14, measuring 25.27 kV (0.766 per unit). However, after the insertion of a DG with a capacity of 7.68 MW and unity power factor, the lowest voltage in the compensated network is 31.61 kV (0.958 per unit) at bus 14. The graphical representation also indicates that the maximum voltage deviation in the compensated network is 4.2%.

Kohalpur-Surkhet primary distribution system		
Case	Base Case	DG with Unity power factor
V_{min} (p.u.)	0.766	0.958
Voltage in kV	25.28	31.61
V_{min} Bus location	14	14
P_{loss} (kW)	1863.33	92.2
Q_{loss} (kVAR)	2130.33	104.3
S_{loss} (kVA)	2843.27	139.21
DG Size(MW)		7.68
DG Location		14

Table 4.4 Comparison of results before and after insertion of DG (unity p.f.) in Kohalpur-Surkhet primary distribution system

4.2.3 Optimum placement of DG with zero power factor

The category of distributed generations (DGs) that are designed to provide reactive power support to the system without contributing to the active power generation is referred to as type-2 DGs with a zero power factor. In this research, these DG units are identified as type-2 DGs. Examples of such generating units include synchronous compensators like gas turbines and capacitors, which are primarily focused on providing reactive power support rather than active power generation.

4.2.3.1 Optimum size of DG at zero factor for each buses in SKPDS.

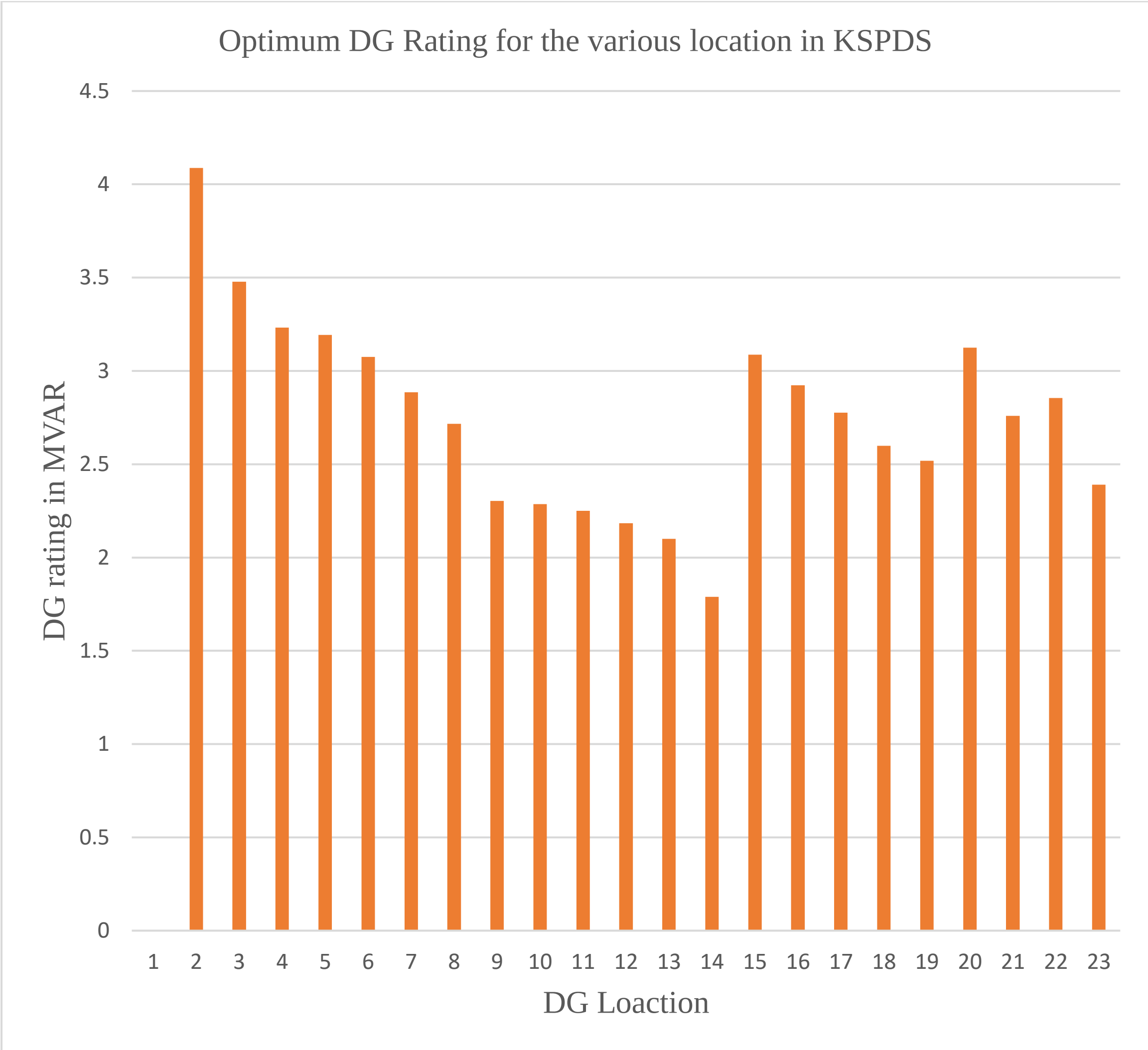

Figure 4. 22 Optimal size of DG (zero p.f.) in KSRDS.

Figure 4.22 presents a bar representation displaying the optimal size of distributed generations (DGs) at all the buses in the practical Kohalpur-Surkhet Primary Distribution

System. The optimal DG sizes range from 1.78 MVAR (at bus location 14) to 4.09 MVAR (at bus location 2). It can be concluded from the figure that the DG sizes do not follow a regular pattern and are independent of the location of the bus, whether it is on the main line or a lateral line.

4.2.3.2 Total real power loss after the placement of optimum size DG (zero power factor) in each bus.

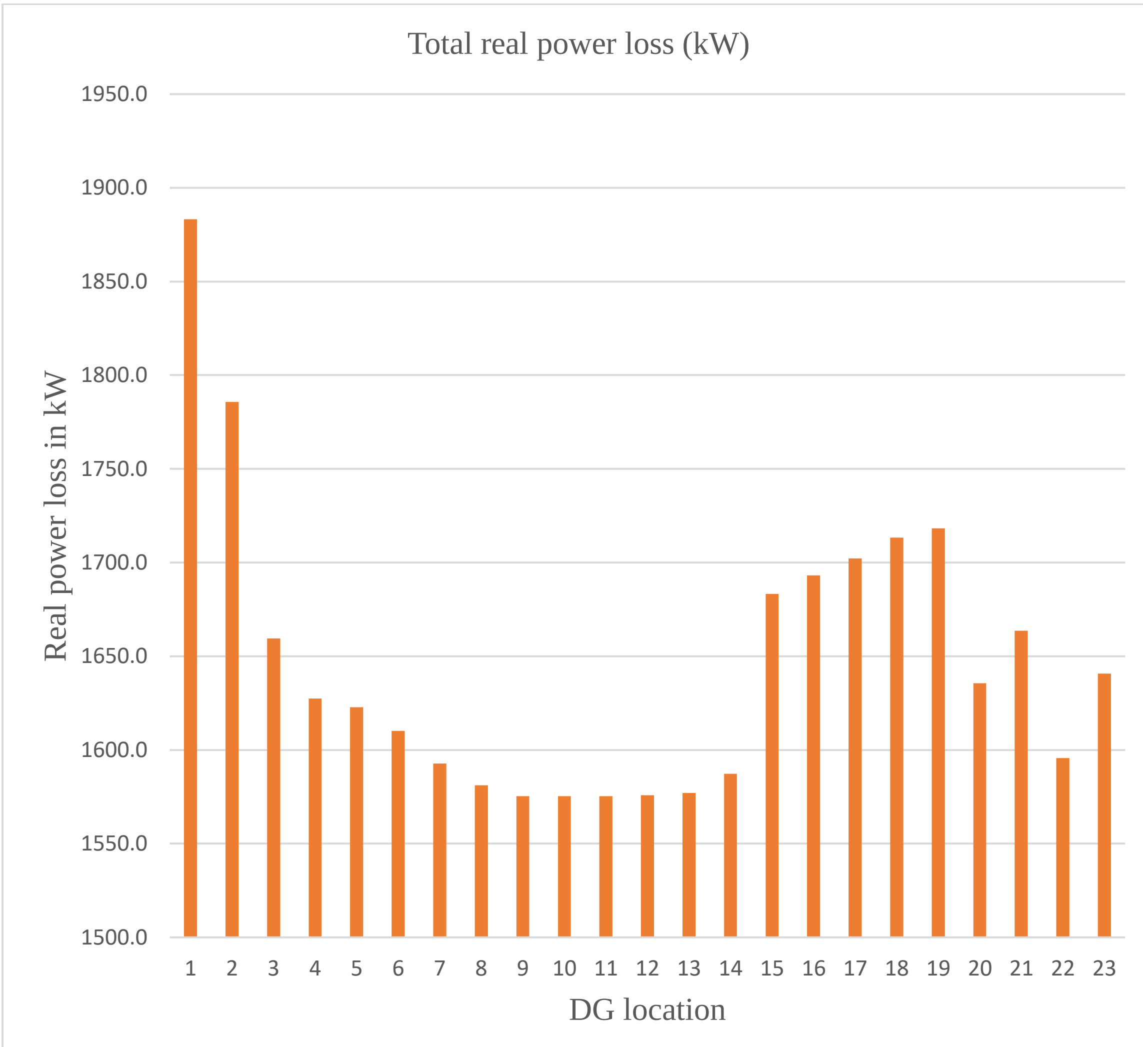

Figure 4. 23 Real power loss after placement of optimum size DG (zero p.f.).

Figure 4.23 illustrates a bar representation depicting the system's total real power loss when optimal size distributed generations (DGs) are placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. The bar representation indicates that the lowest power loss value is approximately 1575.3 kW, which occurs when an optimum size

DG of 2.30 MVAR is placed at bus 9. It is evident from the bar representation that bus 9 is the optimal location for DG placement, and the optimum size of the DG is 2.30 MVAR.

4.2.3.3 Total Reactive power loss after the placement of optimum size DG (zero power factor) in each bus.

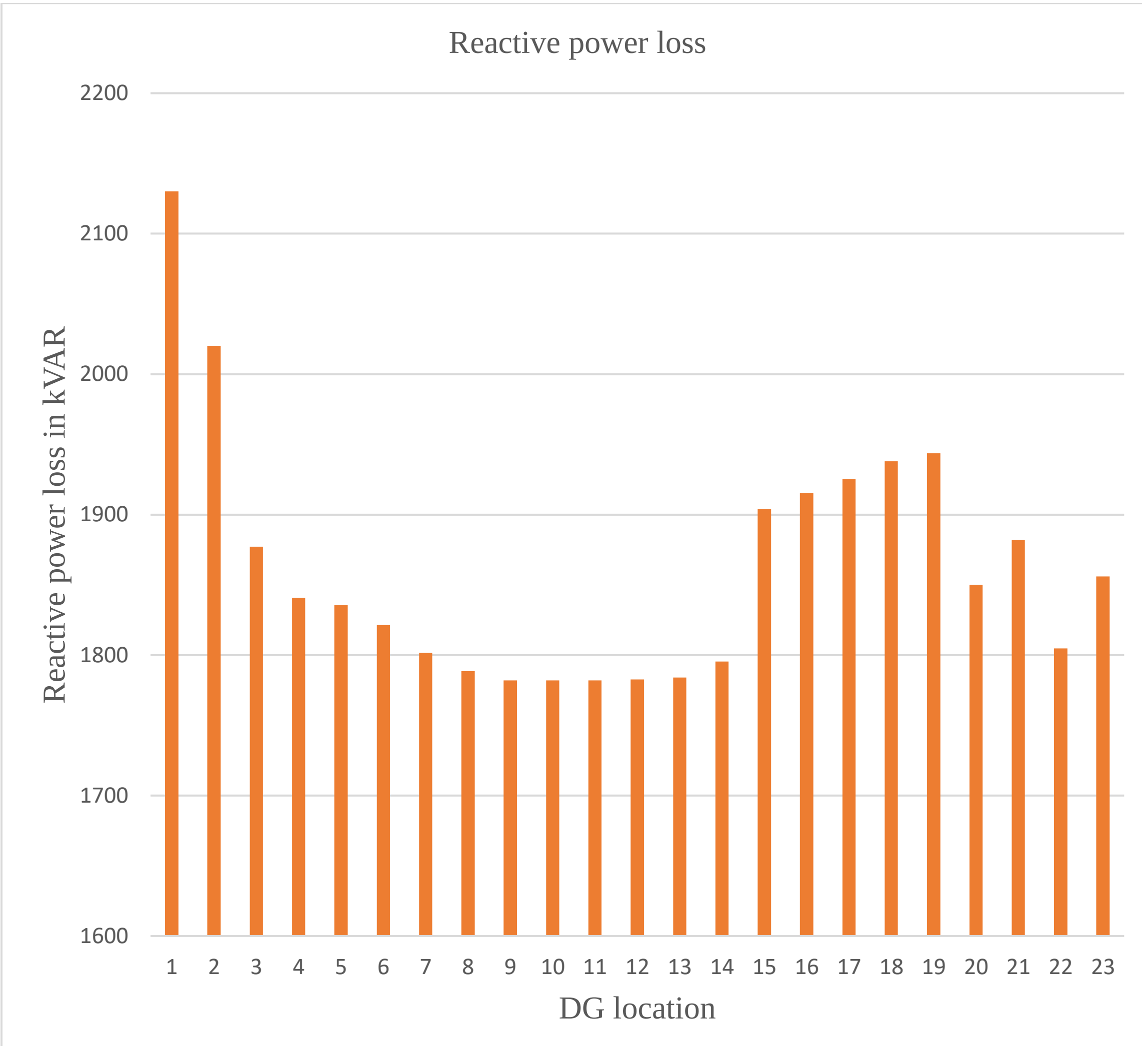

Figure 4. 24 Reactive power loss after the placement of optimum size DG (zero p.f.)

Figure 4.24 presents a bar diagram representing the feeder's total reactive power loss when an optimal size distributed generation (DG) is placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. The bar diagram clearly shows that the lowest loss value is approximately 1781.9 kVAR, which occurs when an optimum size DG of 2.30 MVAR is placed at bus 9. This bar representation confirms that bus 9 is the optimal location for DG placement, and the optimal size of the DG is 2.30 MVAR.

4.2.3.4 Total power loss after the placement of optimum size DG (zero power factor) in each bus.

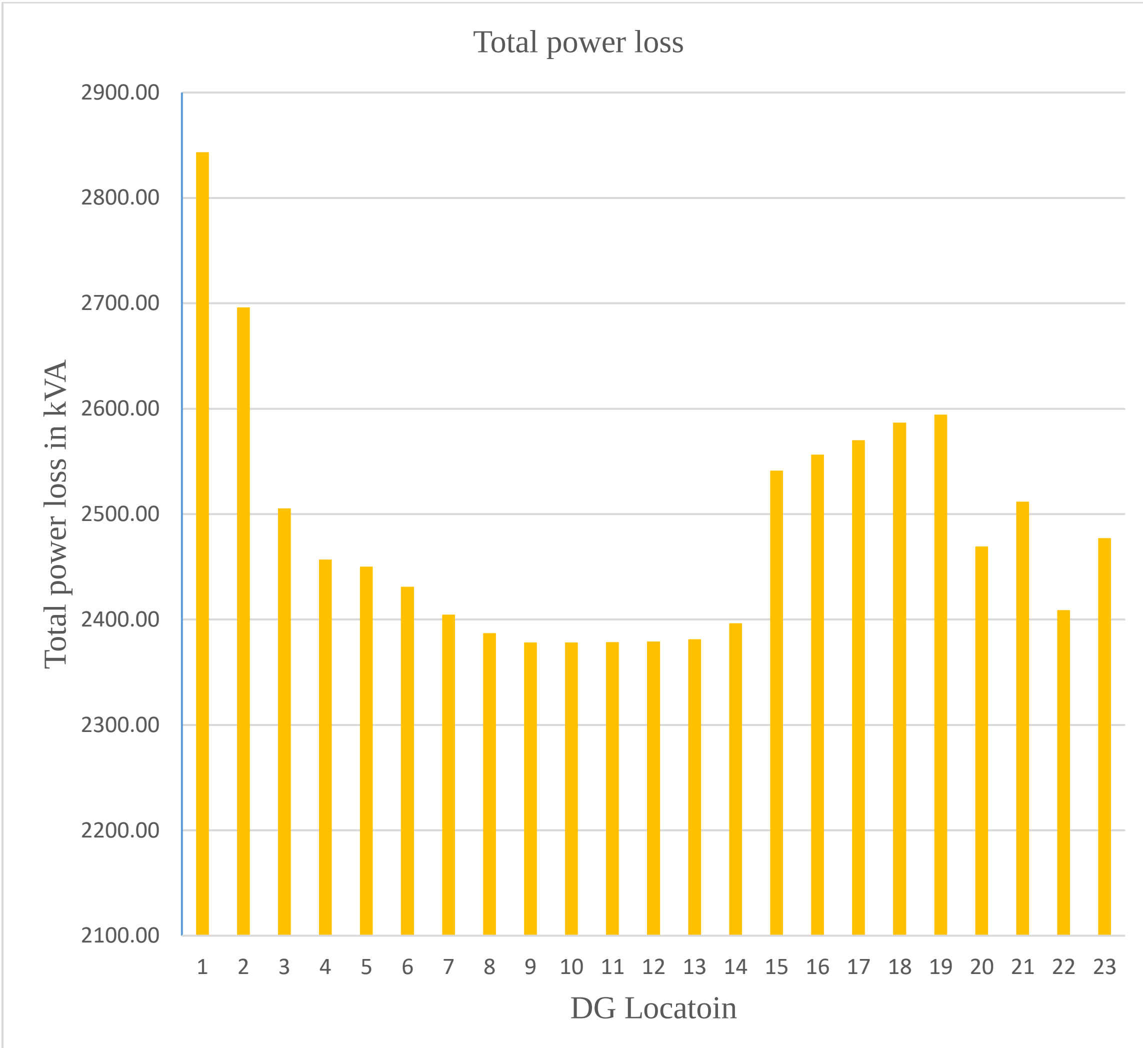

Figure 4. 25 Total power loss after the placement of optimum size DG (zero p.f.)

Figure 4.25 displays a bar diagram representing the feeder's total power loss when an optimal size distributed generation (DG) is placed at each bus in the practical Kohalpur-Surkhet Primary Distribution System. The bar diagram clearly shows that the lowest loss value is approximately 2378.39 kW, which occurs when an optimum size DG of 2.30 MVAR is placed at bus 9. This bar representation further confirms that bus 9 is the optimal location for DG placement, and the optimal size of the DG is 2.30 MVAR.

4.2.3.5 Comparison of voltage before and after the placement of optimum size DG (zero power factor) in each bus.

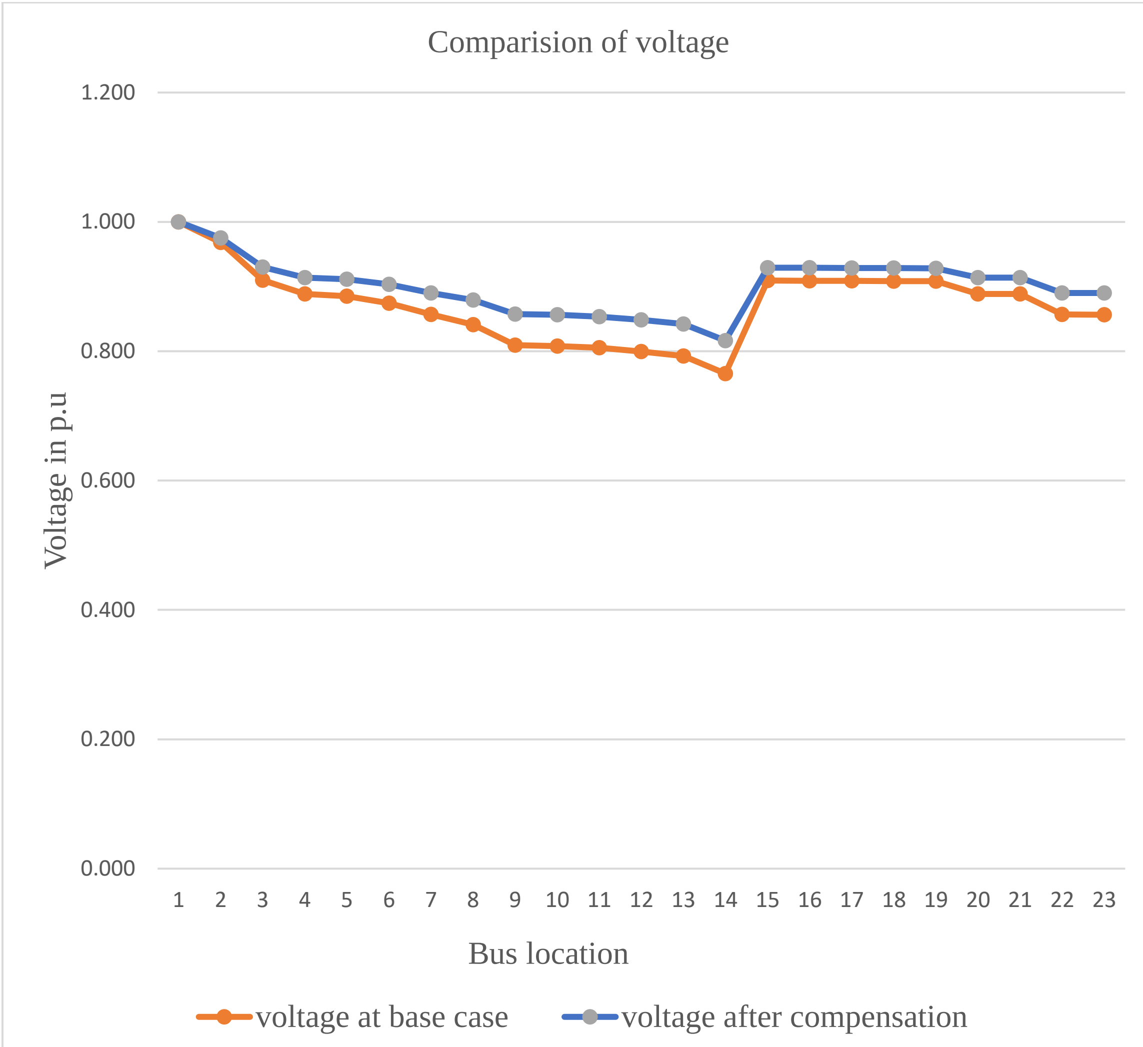

Figure 4. 26 Comparison of voltage before and after placement of DG (zero p.f.)

Figure 4.26 depicts the graphical representation of voltage profiles before and after the placement of DG at bus 9. The voltage levels at each bus have been increased, which is evident from the difference between the orange and blue lines. Prior to the installation of DG, the lowest voltage was recorded at bus 14, measuring 25.27 kV (0.766 p.u.). However, after the DG (2.30 MVAR) with a zero power factor is incorporated into the system, the lowest voltage on the compensated network is observed at bus 14, measuring 26.93 kV (0.816 p.u.). The maximum voltage deviation in the compensated network is 18.4%, signifying the improved voltage stability achieved through the integration of DG.

Kohalpur-Surkhet primary distribution system		
Case	Base Case	DG with zero power factor
V_{min} (p.u.)	0.766	0.816
Voltage in kV	25.28	26.93
V_{min} Bus location	14	9
P_{loss} (kW)	1863.33	1575.3
Q_{loss} (kVAR)	2130.33	1781.9
S_{loss} (kVAR)	2843.27	2378.39
DG Size(MVAR)		2.30
DG Location		9

Table 4.5 Comparison of results before and after insertion of DG (Zero p.f.) in Kohalpur-Surkhet primary distribution system

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The size and location selection of distributed generation is crucial factor in the application of DG for loss reduction and voltage profile improvement. The optimal size and location of distributed generation in radial distribution system is carried using "exact power loss" expression. The algorithms have been developed in MATLAB environment. The line and load data were first stored in Microsoft office excel sheet and the stored data were read from MATLAB. Finally analysis was done on those data in the MATLAB.

The methodology is tested on IEEE 33-bus radial distribution system and finally it is implemented in Kohalpur-Surkhet primary distribution system. The following conclusion could be drawn from the study:

- The voltage received by Budbudi S/S, Surkhet (bus 14) is 25.27 kV during peak load condition i.e. decreased by 23.42% of system voltage.
- The total power losses of Kohalpur-Surkhet 33 kV transmission is 2843.27 kVA during peak load condition (9231.69 MVA) i.e. 30.79%.

5.1.1 When considering the DGs could inject real power only the optimum size and location of Distributed Generations is 7.68 MW and bus 14 respectively. The distribution system loss reduces to 1.5%. The voltage at bus 14 is minimum i.e. 31.61 kV i.e. decreased by 4.21% of system voltage.

5.1.2 When considering the DGs could inject reactive power only the optimum size and location of Distributed Generations is 2.30 MVAR and bus 9 respectively. The distribution system loss reduces to 25.76%.The voltage at bus 9 is minimum i.e. 26.928 kV i.e. decreased by 18.4% of system voltage.

5.1.3 When considering the DGs could inject real and reactive power only (considering 0.85 p.f.) optimal size and location of distributed generation is 7.47 MVA and bus 14 respectively. The distribution system loss reduces to 2.09%. The voltage at bus 19 is minimum i.e. 32.77 kV i.e. decreased by 3% of system voltage.

In summary, the analytical approach proposed in this thesis work allows us to obtain optimal size and location for all types of Distributed Generators (DGs) successfully in radial distribution system. Optimum selection of DG size and location leads reduction in power loss and an improvement in the voltage profile. As a result, the objective of the thesis work was successfully accomplished.

5.2 Recommendation and Future works

This research can be further extended to meet the limitations that are realized while carrying out this thesis. The size and location of Distributed Generations in radial distribution system is carried using "exact power loss" expression and considered at the peak load only. This thesis only presents the analytical approach for the possible best allocation of constant power factor DGs and evenly distributed throughout the network. The active and reactive power of the nodes are assumed to be known and time invariant. However, there are still many areas with future improvement can be done. The areas of probable future work based on the outcomes of this thesis.

- Load modelling and Generator modelling can be taken into account.
- Unbalance system may be taken in account.
- Economic analysis with proper distribution network.

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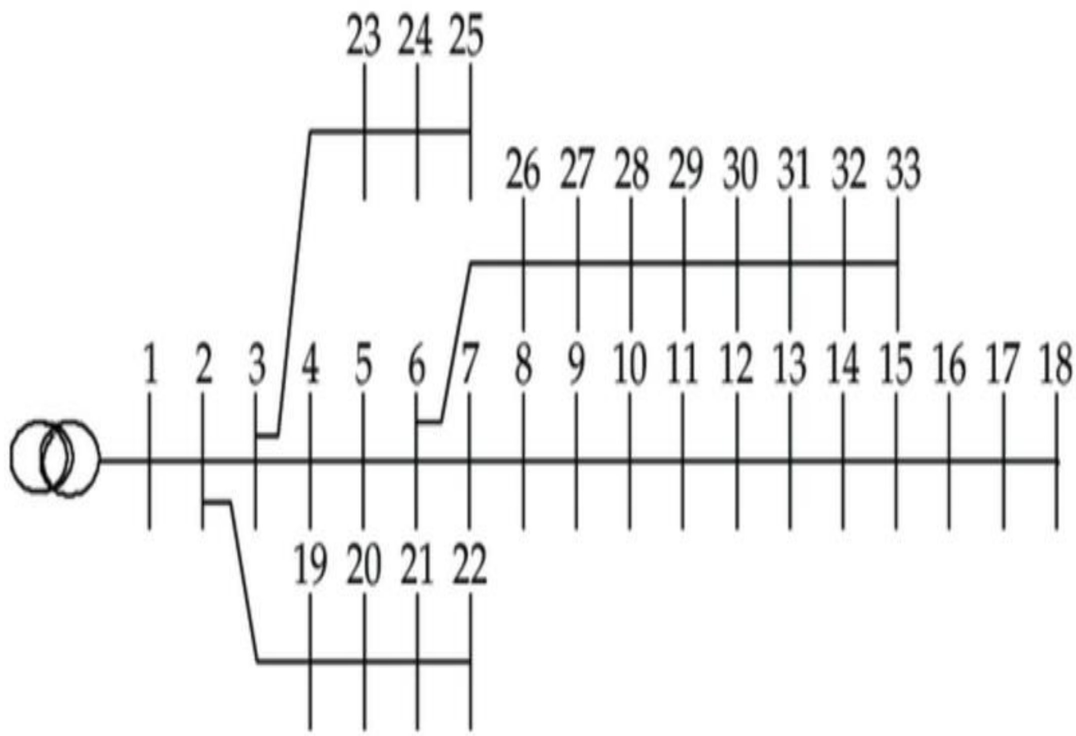
ANNEX – A: IEEE 33 BUS RADIAL DISTRIBUTION SYSTEM FIGURE

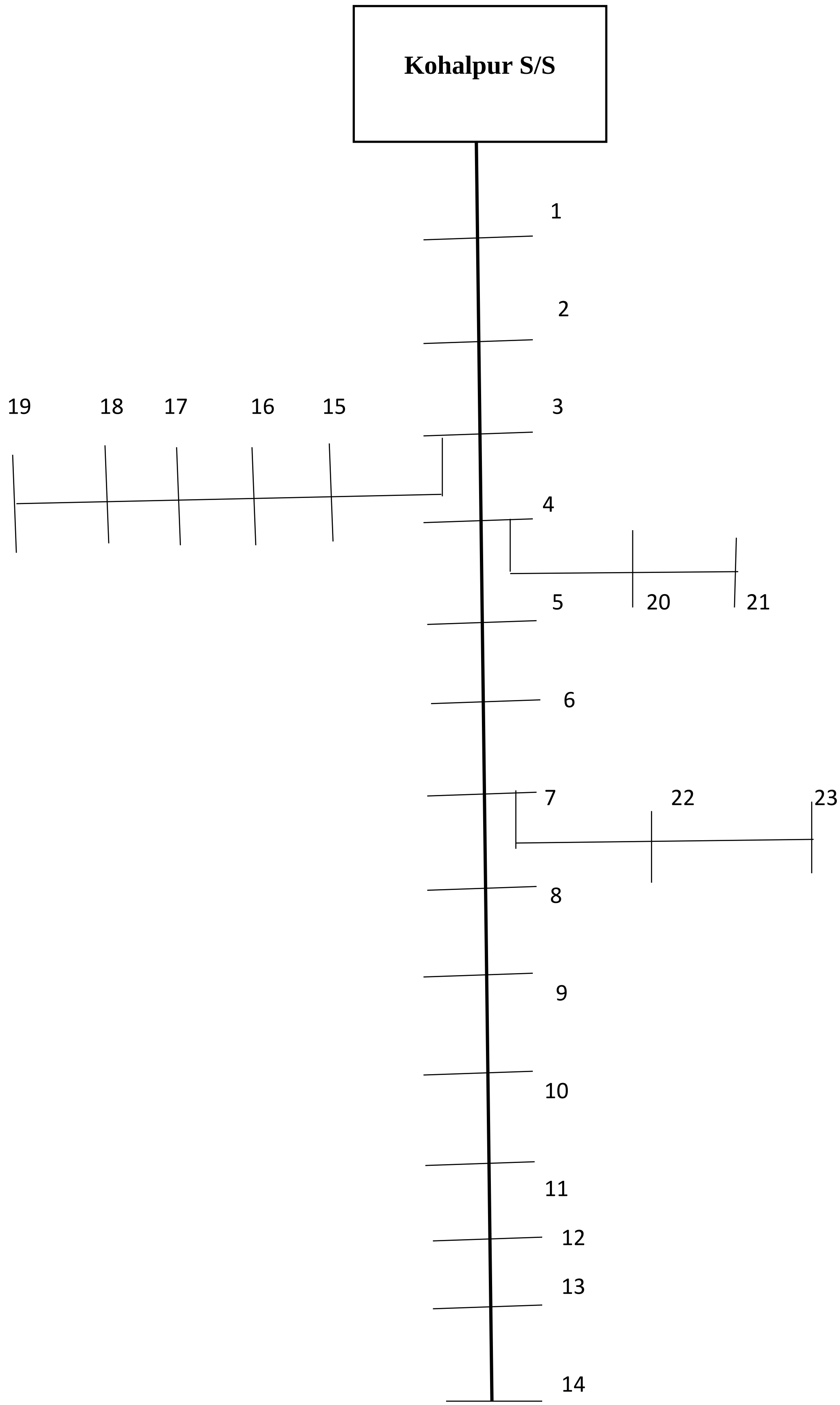


ANNEX – B: IEEE 33 BUS RADIAL DISTRIBUTION SYSTEM DATA

Branch	SN	RN	R(ohm)	X(ohm)	Active(kW)	Reactive(kVAR)
1	1	2	0.092	0.047	100	60
2	2	3	0.493	0.251	90	40
3	3	4	0.366	0.184	120	80
4	4	5	0.381	0.194	60	30
5	5	6	0.819	0.700	60	20
6	6	7	0.187	0.618	200	100
7	7	8	1.711	0.235	200	100
8	8	9	1.030	0.740	60	20
9	9	10	1.040	0.740	60	20
10	10	11	0.196	0.065	45	30
11	11	12	0.374	0.124	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.541	0.712	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.746	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.156	90	40
19	19	20	1.504	1.355	90	40
20	20	21	0.409	0.478	90	40
21	21	22	0.708	0.937	90	40
22	3	23	0.451	0.308	90	50
23	23	24	0.898	0.709	420	200
24	24	25	0.896	0.701	420	200
25	6	26	0.203	0.103	60	25
26	26	27	0.284	0.144	60	25
27	27	28	1.059	0.933	60	20
28	28	29	0.804	0.700	120	70
29	29	30	0.507	0.258	200	600
30	30	31	0.974	0.963	150	70
31	31	32	0.310	0.361	210	100
32	32	33	0.341	0.530	60	40

ANNEX – C: KOHALPUR-SURKHET 33 KV LINE PARAMETER

Branch no	SN	RN	R	X	P	Q
1	1	2	2.196	2.484	85	50
2	2	3	4.117	4.657	11	5
3	3	4	1.647	1.863	22	8
4	4	5	0.274	0.310	11	6
5	5	6	0.823	0.931	22	10
6	6	7	1.372	1.552	22	9
7	7	8	1.235	1.397	1200	400
8	8	9	3.019	3.415	50	15
9	9	10	0.137	0.155	35	13
10	10	11	0.274	0.310	50	15
11	11	12	0.549	0.621	35	15
12	12	13	0.686	0.776	50	18
13	13	14	2.745	3.105	6500	1500
14	3	15	0.823	0.931	35	10
15	15	16	0.411	0.465	25	6
16	16	17	0.411	0.465	210	55
17	17	18	0.549	0.621	30	5
18	18	19	0.274	0.310	350	70
19	4	20	0.274	0.310	21	8
20	20	21	1.098	1.242	27	10
21	7	22	0.109	0.124	22	8
22	22	23	2.058	2.328	135	35


Kohalpur S/S
1
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MATLAB Program

Main program

```
clear all
clear
filename='33bus.xlsx';

%filename='skt1.xlsx';

filename1='33bus1.xlsx';

%filename1='skt2.xlsx'

sheet=1
format short
a=xlsread(filename);   a2=xlsread(filename1);
branch=a(:,1);
SN=a(:,2);
RN=a(:,3);             Node=a2(:,2);
r=a(:,4);              r2=a2(:,3);
xl=a(:,5);              xl2=a2(:,4);
p=a(:,6);               p2=a2(:,5);
q=a(:,7);               q2=a2(:,6);
          TYPE=a2(:,7);
% changing p,q,R,XL in p.u.
bMVA=100
%bKVA=100kVA
bKV=33;
%bKV=12.66
P=p/(1000*100);                    P2=p2/100000;
Q=q/(1000*100);                    Q2=q2/100000;
S=complex(P,Q);           S2=complex(P2,Q2)



% changing the value of z in pu
z=complex(r,xl);             z2=complex(r2,xl2);

Zb=(bKV^2)/bMVA;
Z=z/Zb;
Z2=z2/Zb;

% calling bibcnbcbv function
[X,Y] = bibcnbcbv(branch,RN,SN,Z)
DLF=Y*X;
% calling load flow program for finding voltage and current at each
buses
[V] = loadflow(SN,S,DLF)
xlswrite('outputdata.xls',SN(:,1),'base','A5');
xlswrite('outputdata.xls',RN(:,1),'base','B5');
xlswrite('outputdata.xls',V(:,1),'base','C5');
%computation of node voltage
Vabs=abs(V);
delta=angle(V);
```

```
C=conj(S./V);
%computation of branch current
BC=X*C;
brloss=abs(BC.*BC).*Z;
realbrloss=real(brloss);

reacbrloss=imag(brloss);

xlswrite('outputdata.xls',realbrloss(:,1),'base','D5')
xlswrite('outputdata.xls',reacbrloss(:,1),'base','E5')
%figure;
plot(branch,Vabs)

% finding branch real ahelp xlebelnd reactive power loss
% calling the optimum capacitor placement program
%[coptcurrent,maxlossred] = optcap(branch,RN,SN,Z,BC)
[lsenfact,Norm] = lsf(Vabs,X,Z,Q,branch);
flag=zeros(max(branch),1);
for i=1:max(branch)
    if Norm(i,1)>1.01
        flag(i,1)=0;
    else
        flag(i,1)=1;
    end
end
T =
sortrows((table(RN,Vabs,C,realbrloss,reacbrloss,lsenfact,Norm,flag)),6,
'descend');

%T = sortrows(T,5,'descend')
A = real(table2array(T));
xlswrite('lsenfact.xlsx',A);
probbus=0;
[row,column]=size(A);
 for i=1:row
     if A(i,column)==1
         probbus(1,i)=A(i,1);
     end
 end
 %elimination of flag=0 and finding problocation
 problocation = probbus(probbus>0)
 bactloss=abs(BC.*BC)'*real(Z)
breacloss=abs(BC.*BC)'*imag(Z)
% calling Zbus formation program
%[ Z ] = Zbusformation(AA,type,sn,rn,zz)
% powerloss reduction program
%[ Vabs,delta ] = rectopolar(V)

 [ Zbus ] = Zbusformation( TYPE,SN,RN,Z )
 %calling parameter alpha,beta,Xi,Yi for finding the value of DG
inserted
 %in each node for minimum loss.

 P2(1)=-(sum(P2)+bactloss);
 Q2(1)=-(sum(Q2)+breacloss);
```

```
[alpha,beta,Xi,Yi ] = parameter( P2,Q2,V,delta,Zbus )
[ PDGI,QDGI ] = DGvalue( RN,P2,Q2,Xi,Yi,S2,V,delta,Zbus)
% finding the total value of power loss in a compensated network

DGrating=complex(PDGI,QDGI)
[row,column]=size(S2)
Pdnew=zeros(row,1)
for i=1:row
   for j=1:row
       if i==j
           Pdnew(i,j)=S2(i,1)-DGrating(i,1)
       else
           Pdnew(i,j)=S2(i,1)
       end
   end
end

Pdnew(1,:)=[];
for o=1:row
    V1(:,o) = loadflow(SN,Pdnew(:,o),DLF)
    C1(:,o)=conj(Pdnew(:,o)./V1(:,o));
    BC1(:,o)=X*C1(:,o);
    bactloss1(:,o)=abs(BC1(:,o).*BC1(:,o))'*real(Z);
    breacloss1(:,o)=abs(BC1(:,o).*BC1(:,o))'*imag(Z);
end
V1abs=abs(V1)
```

Function1: BIBC and BCBV matrix formation

```
function [X,Y] = bibcnbcbv(branch,RN,SN,Z)
%filename='loaddata.xlsx';
%sheet=1
%a=xlsread(filename);
%branch=a(:,1);
%SN=a(:,2);
%RN=a(:,3);
% for BIBC matrix
n=max(branch);
m=max(RN);
BIBC=zeros(n,m-1);

for i=n:-1:1
    s=SN(i,1);
    r=RN(i,1);
    BIBC(i,r-1)=1;
    indexRN=find(SN==r);
    [row colum]=size(indexRN);
       for k=1:row
        if row~=0
    BIBC(i,:)=BIBC(i,:)+BIBC(indexRN(k,1),:);
        else
```

```
            Display('no furter sending end');

        end
       end
end

% for BCBV matrix

BCBV=zeros(n,m-1);
for i=1:n
    s=SN(i,1);
    r=RN(i,1);
    BCBV(i,i)=Z(i,1)
    indexSN=find(RN==s);
    [row colum]=size(indexSN);
       for l=1:row
        if row~=0
    BCBV(i,:)=BCBV(i,:)+BCBV(indexSN(l,1),:);
       else
           Display('no furter sending end');

        end
       end
end
X=BIBC
Y=BCBV
```

Function2: Load flow program

```
function [V] = loadflow(SN,S,DLF)
% computation of voltage and current at each node
%finding the size of V
V=ones(max(SN),1);
%finding the size of C
C=ones(max(SN),1);
%updating the value of C
C=conj(S./V);
%finding the value of dV
dV=DLF*C;
%updating the value of v
V=1-dV;
error=0.00001;
for k=1:1:500
    co=C;
    C=conj(S./V);
    %finding difference between base condition and k=1 with C from 16
using
    %12
    terror=max(C-co);
    dV=DLF*C;
    V=1-dV;
    if terror<error
        break
    end
```

```
end
iteration=k;
return
```

Function3: LSF Program

```
function [lsenfact,Norm] = lsf(Vabs,X,Z,Q,branch);
n=max(branch);
for i=1:n
Norm=zeros(n,1);
lsenfact=zeros(n,1);
for i=1:n
 lsenfact(i,1)=(2*(Q'*X(i,:)')*real(Z(i,1)))/((Vabs(i))^2);
 Norm(i,1)=Vabs(i,1)/0.95;
end
end
```

Function4: Zbus formation

```
function [ Zbus ] = Zbusformation( TYPE,SN,RN,Z )



         z= -200i;

for a=1:length(SN)


    b=RN(a);


    st=SN(a);
    [rw, cl]=size(z);
      z(:,cl+1)=z(:,st);
     z(rw+1,1:cl)=z(st,1:cl);
     z(rw+1,cl+1)=z(st,st)+Z(a);




end
Zbus=z;

end
```

Function5: DG rating

```
function [ PDGI,QDGI ] = DGvalue( RN,P2,Q2,Xi,Yi,S2,V,delta,Zbus)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
% no of buses i.e. buses other than substation
```

```
Vp=[1;V];
Vabsp=abs(Vp);
deltap=[0;delta];

n=max(RN);
PDGI=zeros(n,1);
QDGI=zeros(n,1);

Alpha=zeros(n,n);
Beta=zeros(n,n)
for i=1:n
    for j=1:n
    Alpha(i,j)=((real(Zbus(i,j))/(Vabsp(i)*Vabsp(j)))*cos(deltap(i)-
deltap(j)))
     beta(i,j)=((real(Zbus(i,j))/(Vabsp(i)*Vabsp(j)))*sin(deltap(i)-
deltap(j)))
    end
end


    pf=input('enter the value of pf: ');
if pf==1
for i=1:n
    PDGI(i,1)=P2(i,1)-(((Beta(i,i)*Q2(i,1))+Xi(i,1))/Alpha(i,i));

end
end
if pf==0
    for i=1:n
    QDGI(i,1)=Q2(i,1)+(((Beta(i,i)*P2(i,1))-Yi(i,1))/Alpha(i,i));
    end
end
if (0<pf && pf<1)
    for i=1:n
        aa=tan(acos(pf));

PDGI(i,1)=((Alpha(i,i)*(P2(i,1)+aa*Q2(i,1)))+((Beta(i,i)*(aa*P2(i,1)-
Q2(i,1)))-Xi(i,1)-aa*Yi(i,1)))/(Alpha(i,i)*(aa^2+1));
    QDGI(i,1)=aa*PDGI(i,1);
    end
end

if (-1<pf && pf<0)
    for i=1:n
        aa=tan(acos(pf));

PDGI(i,1)=((Alpha(i,i)*(P2(i,1)+aa*Q2(i,1)))+((Beta(i,i)*(aa*P2(i,1)-
Q2(i,1)))-Xi(i,1)-aa*Yi(i,1)))/(Alpha(i,i)*(aa^2+1));
   QDGI(i,1)=aa*PDGI(i,1);
    end

end

end
```

Voltage Profile Improvement and Power Loss Reduction by DG Placement in a Distribution Feeder in Western Nepal

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